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Improving Area-Controlled Error and Frequency Stability for Electric Vehicle Charging System

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***ABSTRACT*:** Electric Vehicles (EVs) are gaining momentum due to several factors, including the price reduction as well as the climate and environmental awareness. This paper reviews the advances of EVs regarding battery technology trends, charging methods, as well as new research challenges and open opportunities. More specifically, an analysis of the worldwide market situation of EVs and their future prospects is carried out. One of the fundamental aspects in EVs is the battery, the paper presents a thorough review of the battery technologies—from the Lead-acid batteries to the Lithium-ion. Moreover, we review the different standards that are available for EVs charging process, as well as the power control and battery energy management proposals. Finally, we conclude our work by presenting our vision about what is expected in the near future within this field, as well as the research aspects that are still open for both industry and academic communities.

Keywords: Electric Vehicles; Plug-In Hybrid Electric Vehicle; battery charging; batteries technology; charging modes; EV plugs.

I.Introduction

The automotive industry has become one of the most important world-wide industries, not only at economic level, but also in terms of research and development. Increasingly, there are more technological elements that are being introduced on the vehicles towards the improvement of both passengers and pedestrians' safety. In addition, there is a greater number of vehicles on the roads, which allows for us to move quickly and comfortably. However, this has led to a dramatic increase in air pollution levels in urban environments (i.e., pollutants, such as PM, nitrogen oxides (NO_X), CO, sulfur dioxide (SO_2), etc.).

EVs offer the following advantages over traditional vehicles:

- Zero emissions: this type of vehicles neither emit tailpipe pollutants, CO_2, nor nitrogen dioxide (NO_2). Also, the manufacture processes tend to be more respectful with the environment, although battery manufacturing adversely affects carbon footprint.
- Simplicity: the number of Electric Vehicle (EV) engine elements is smaller, which leads to a much cheaper maintenance. The engines are simpler and more compact, they do not need a cooling circuit, and neither is necessary for incorporating gearshift, clutch, or elements that reduce the engine noise.
- Reliability: having less, and simpler, components makes this type of vehicles have fewer breakdowns. In addition, EVs do not suffer of the inherent wear and tear produced by engine explosions, vibrations, or fuel corrosion.
- Cost: the maintenance cost of the vehicle and the cost of the electricity required is much lower in comparison to maintenance and fuel costs of traditional combustion vehicles.
- The energy cost per kilometer is significantly lower in EVs than in traditional vehicles.
- Comfort: traveling in EVs is more comfortable, due to the absence of vibrations or engine noise.
- Efficiency: EVs are more efficient than traditional vehicles. However, the overall well to wheel (WTW) efficiency will also depend on the power plant efficiency.

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For instance, total WTW efficiency of gasoline vehicles ranges from 11% to 27%, whereas diesel vehicles range from 25% to 37%. By contrast, EVs fed by a natural gas power plant show a WTW efficiency that ranges from 13% to 31%, whereas EVs fed by renewable energy show an overall efficiency up to 70%.

- Accessibility: this type of vehicle allows for access to urban areas that are not allowed to other combustion vehicles (e.g., low emissions zones). EVs do not suffer from the same traffic restrictions in large cities, especially at high peaks of contamination level. Interestingly, there was a recent OECD study that suggests that, at least in terms of Particulate Matter (PM) emissions, EVs will unfortunately not improve the air quality situation.

Electric Vehicles (EVs) can be classified into several categories based on various factors such as:

1. Type of Electric Motor:

- DC Motor EVs

- AC Motor EVs

- Permanent Magnet Motor EVs

2. Source of Electricity:

- Battery Electric Vehicles (BEVs)

- Hybrid Electric Vehicles (HEVs)

- Plug-in Hybrid Electric Vehicles (PHEVs)

- Fuel Cell Electric Vehicles (FCEVs)

3. Range and Distance:

- Short-range EVs (less than 100 km)

- Medium-range EVs (100-200 km)

- Long-range EVs (more than 200 km)

4. Charging Method:

- Level 1 (120V, 12A)

- Level 2 (240V, 32A)

- DC Fast Charging

5. Vehicle Type:

- Passenger EVs

- Commercial EVs (vans, trucks, buses)

- Two-wheelers (electric motorcycles, scooters)

6. Battery Type:

- Lead-Acid Batteries

- Nickel-Metal Hydride (NiMH) Batteries

- Lithium-Ion (Li-ion) Batteries

Hybridization:

- Series Hybrid

- Parallel Hybrid

- Mild Hybrid

8. Autonomy:

- Level 0 (no automation)

- Level 1 (driver assistance)

- Level 2 (partial automation)

- Level 3 (conditional automation)

- Level 4 (high automation)

- Level 5 (full automation)

These classifications help to differentiate EVs based on their characteristics, performance, and applications.

II. Challenges of Electric Vehicle Charging

Purchase Cost: Electric vehicles are more expensive to build than gasoline-powered ones, primarily because of battery technology.

- **Range Anxiety:** Americans are used to jumping in their cars and going wherever they want without worrying about finding a gas station for a quick fill-up when needed.

- Limited Selection: There is still a limited selection of EVs compared to gasoline-powered cars.

- Difficulty Finding a Technician: With the EV industry still comparatively small, there are relatively few trained EV repair technicians and even fewer qualified independent shops.

- Charging Infrastructure: The scarcity of charging stations in many areas of the country is increasing the incidence of range anxiety.

- Charging Speeds: Charging electric cars can be a problem for drivers who have trouble adjusting to the EV lifestyle, which can dictate a slower pace of life.

- Charger Compatibility: Level 2 chargers are mostly coordinated, with all automakers except Tesla using the same type of charging port. However, there are three different types of DC fast chargers.

- Grid Capacity: Changing to EVs means millions of people will rely on the electric grid in new ways, and grid capacity will need to increase to avoid strain.

- Charging Station Financing and Ownership: Public EV charging stations can be expensive to install.

- Charging Price Structures: EV charging includes several different pricing structures, unlike gasoline which is always priced by the gallon.

- Electric Vehicles offer numerous advantages such as decreasing pollution levels and reduction in oil import bills, but there is considerable amount of threats in establishing the Electric Vehicles in India.

- The major pollutants emitted from the automobiles are hydrocarbons, nitrogen dioxide, lead, carbon monoxide, Sulphur dioxide, and particulate matter.

power system operation, system reliability, and efficiency.

Large frequency deviations can damage equipment, degrade load performance, overload transmission lines, and interfere with system protection schemes. These large-frequency deviation events can ultimately lead to a system collapse. Variation in frequency adversely affects the operation and speed control of induction and synchronous motors. The reduced speed of motor-driven generating station auxiliaries, associated with the fuel, the feed-water, and the combustion air supply systems, such as fans, pumps, and mills, will bring down plant output. The considerable drop in frequency could result in high magnetizing currents in induction motors and transformers thereby increasing reactive power consumption. The extensive use of electric clocks and the use of frequency for other timing purposes require accurate maintenance of synchronous time, which is proportional to the integral of frequency.

II Need for Load Frequency Control

For large scale, electric power systems with interconnected areas, Load Frequency Control (LFC) is important to keep the system frequency and the inter-area tie power as near to the scheduled values as possible. The input mechanical power to the generators is used to control the frequency of output electrical power and to maintain the power exchange between the areas as scheduled. A well designed and operated power system must cope with changes in the load and with system disturbances, and it should provide an acceptable high level of power quality while maintaining both voltage and frequency within tolerable limits. Load frequency control is a basic control mechanism in the power system operation. Whenever there is variation in load demand on a generating unit, there is a momentarily an occurrence of an unbalance between real-power input and output.

This difference is being supplied by the stored energy of the rotating parts of the unit. Load Frequency Control (LFC) is being used for several years as part of the Automatic Generation Control (AGC) scheme in electric power systems. One of the objectives of AGC is to maintain the system frequency at a nominal value (50 Hz).

A power system consists of a governor, a turbine, and a generator with the feedback of regulation constant. The system also includes step load change input to the generator. This work mainly, related to the controller unit of a two-area power system. The load frequency control strategies have been suggested based on the conventional linear Control theory. These controllers may be unsuitable in some operating conditions due to the complexity of the power systems such as nonlinear load characteristics and variable operating points. To some authors, variable structure control maintains the stability of system frequency. However, this method needs some information for system states, which are very difficult to know completely. Also, the growing needs of complex and huge modern power systems require the optimal and flexible operation of them. The dynamic and static properties of the system must be well known to design an efficient controller.

Under the normal operating condition, the controller is set for small changes in load demand without voltage and frequency exceeding the pre-specified limits. If the operating condition changes by any cause, the controller must be reset either manually or automatically. The objective of the load frequency controller is to exert the control of frequency and at the same time real power exchange via an outgoing transmission line. The frequency is sensed by a frequency sensor. The change in frequency and tie-line real power can be measured by a change in rotor angle δ. The load frequency controller amplifies and transforms the error signal, i.e., (Δf_i) into real power command signal ΔP_{ci}, which is sent to the prime mover via governor (that controls the valve mechanism).

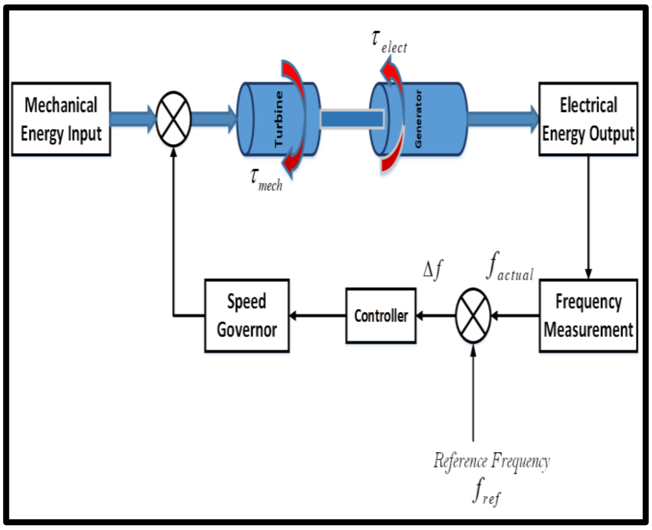

Fig.1 The AGC system

III. Methodology

A complete block diagram representation of an isolated power system comprising the turbine, generator, governor, and load is easily obtained by combining the block diagrams of individual components.

In this case, no controller action is applied because of actual system performance due to a step change of load. The dynamic behavior for the nominal system as the change in frequency consists of Hydraulic Amplifier, Turbine, and Generator model as shown in Fig2.

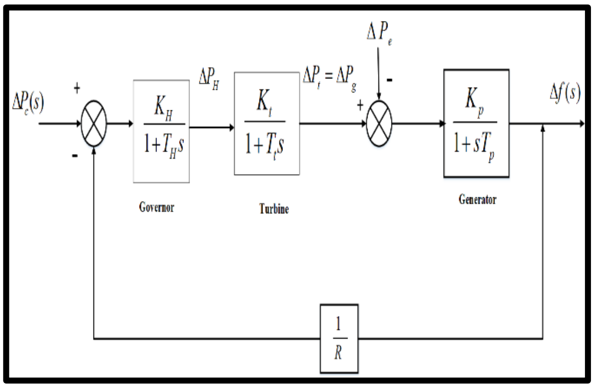

Fig.2 Block Diagram of Load Frequency Control

Fig. 2 can be modeled in the state space form with the help of the following matrix equation:

$$\dot{x} = Ax + Bu + F\rho \qquad (1)$$

Here,

$$A = \begin{bmatrix} -\frac{1}{T_p} & \frac{K_p}{T_p} & 0 \\ 0 & -\frac{1}{T_t} & \frac{1}{T_t} \\ \frac{1}{RT_H} & 0 & -\frac{1}{T_H} \end{bmatrix} \quad (2)$$

$$B = \begin{bmatrix} 0 \\ 0 \\ \frac{1}{T_H} \end{bmatrix} \quad (3)$$

$$f = \begin{bmatrix} -\frac{K_p}{T_p} \\ 0 \\ 0 \end{bmatrix} \quad (4)$$

$$\rho = [\Delta P_E] \quad (5)$$

Here,

x^T = State vectors, $[\Delta f \quad \Delta P_T \quad \Delta P_H]$

u = Control vector, it is zero in uncontrolled case.

IV. Introduction to Electric Vehicles

This India does not have adequate petroleum reserves. Therefore, it is heavily dependent on crude oil and natural gas imports. Presently, India is the third-biggest oil importer after the US and China. The total crude basket of India includes 82.8% import of crude oil and 45.3% import for natural gas. As petroleum products consumption contributes to air pollution, there has been a huge demand to contain the consumption of petroleum products to address the pollution problem. Further, it also causes a huge economic burden on Indian citizens due to the large size of crude oil imports. Therefore, to reduce the dependence on petroleum products and save the environment, it is required to switch over to alternate clean fuel and clean technology.

A major portion of the petroleum products is being consumed by motorized vehicles. Hence, running these vehicles is causing major damage to our environment by adding air pollution. As the Indian transport sector is heavily dependent on petroleum products, the technologies like battery-powered Plug-in Electric Vehicle (PEV) and Plug-in Hybrid Electric Vehicle (PHEV) are gaining momentum to combat greenhouse gas emissions and air pollution. The vehicles in which charging takes place from an external source of power supply, such as the electric grid, are called plugin electric vehicles (PEV). The Plug-in Hybrid Electric Vehicle (PHEV), on the other hand, comprises both plug-in electric vehicle systems to charge from an electrical power source and a petrol/diesel engine which acts as a backup power source to charge the battery and run the electric motor of the vehicle. To connect EVs to the electric grid, power electronics controllers based on Electric Vehicle Supply Equipment (EVSE) are required. The onboard AC to DC converter, with single or three-phase connectors, is an integral part of these controllers. Recently, a lot of new EV charging technologies are being developed and deployed commercially across the globe [9]. This enables EVs to get charged at a very fast rate. In the future, there will be further innovations in the development of ultra-fast charging technologies for EVs, which will enable a large size of EVs to be charged in a few minutes. Although the fast-changing technology for the EV makes vehicle owners comfortable in getting their vehicle charged quickly, it may pose a lot of challenges in the smooth functioning of the electrical power distribution system (EPDS). Further, charging a large number of EVs simultaneously from the grid may also cause various power system operational challenges due to higher peak load demands and system harmonics. Therefore, it is required to analyze the impact of a large number of EV charging on the EPDS. In this work, key challenges to be faced by EPDS operators, due to massive EV charging load, are highlighted.

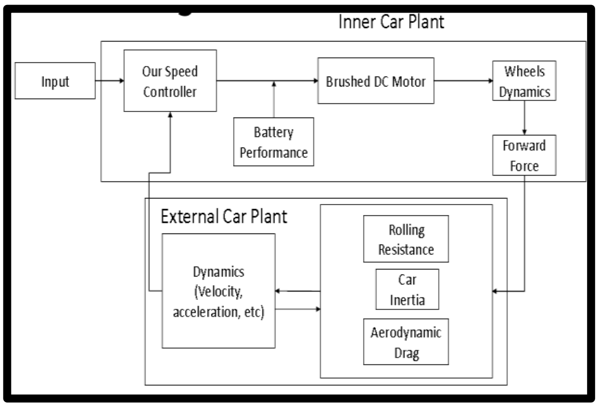

Fig.3 Model Diagram for EV

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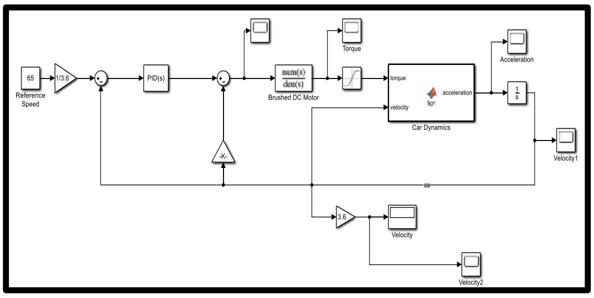

Fig.4 Simulink Model for EV

Mathematical Modelling of EVs:

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

$$V(t) = I(t) * R + L * \frac{dI}{dt} + K_E * \omega(t) \quad (6)$$

Transforming this equation to the Laplace domain, we get:

$$V(s) = R * I(s) + sL * I(s) + K_E * \omega(s) \quad (7)$$

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

$$T(s) = K_T * I(s) \quad (8)$$

Hence, we can write:

$$I(s) = \frac{V(s) - K_E * \omega(s)}{sL + R} \quad (9)$$

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

$$T(s) = K_T * \frac{V(s) - K_E * \omega(s)}{sL + R} \quad (10)$$

The control methodology proposed in this work is the ANFIS. ANFIS stands for Adaptive Neuro-Fuzzy Inference System. The ANFIS controller combines the advantages of a fuzzy controller as well as the quick response and adaptability nature of ANN Fundamentally, ANFIS is about taking a fuzzy inference system (FIS) and tuning it with a backpropagation algorithm based on some collection of input-output data. This allows your fuzzy systems to learn. A network structure facilitates the computation of the gradient vector for parameters in a fuzzy inference system. Once the gradient vector is obtained, several optimization routines are applied to reduce an error measure. This process is called learning by example in the neural network literature.

The fuzzy inference system that has been considered is a model that maps:

– Input characteristics to input membership functions,
– Input membership function to rules,
– Rules to a set of output characteristics,
– Output characteristics to output membership functions, and
– The output membership function to a single-valued output, or
– A decision associated with the output.

Only membership functions have been considered that have been fixed and somewhat arbitrarily chosen. Also, the only fuzzy inference is applied for modeling systems whose rule structure is essentially predetermined by the user's interpretation of the characteristics of the variables in the model. In general, the shape of the membership functions depends on parameters that can be adjusted to change the shape of the membership function. The parameters can be automatically adjusted depending on the data that has been tried to model.

Mathematical Modelling of ANFIS

While there are several algorithms to train the ANN/ANFIS model, yet one of the fasters and most efficient algorithms is the Levenberg Marqardt (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. Considering the gradient of the error with respect to weights for a loss minimization, we obtain the derivative gradient as:

$$g = \frac{\partial E(x,w)}{\partial x} = \begin{bmatrix} \frac{\partial E}{\partial w_1} & \frac{\partial E}{\partial w_2} & \dots & \frac{\partial E}{\partial w_N} \end{bmatrix}^T \quad (11)$$

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

$$w_{k+1} = w_k - \left[J_k J_k^T + \mu I\right]^{-1} J_k^T e_k \quad (12)$$

Here,
k is the iteration number
w_{k+1} is weight of next iteration,
w_k is weight of 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 with respect to weights
J_k^T is Transpose of Jacobian Matrix
e_k is error of 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:

$$MSE = \frac{1}{N}\sum_{t=1}^{N} {e_t}^2 \quad (13)$$

The mean absolute percentage error can also be computed as:

$$MAPE = \frac{100}{N}\sum_{t=1}^{N}\frac{|V_t - \hat{V}_t|}{V_t} \quad (14)$$

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:

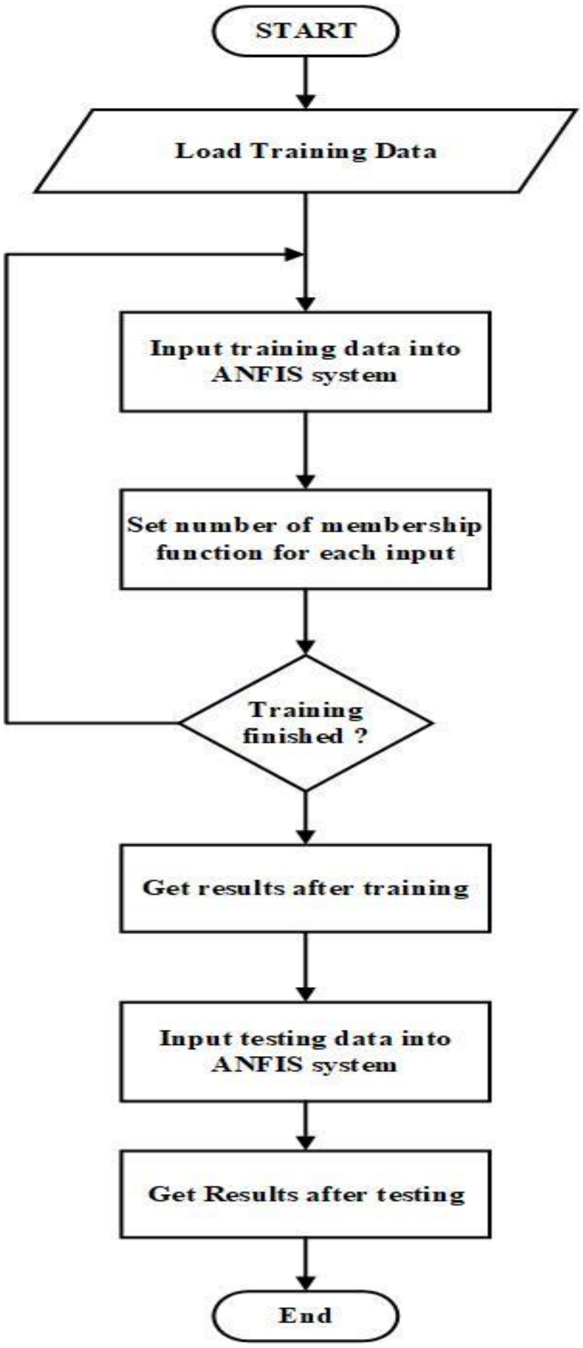

Fig.5 ANFIS Flowchart

IV. Results and Discussions

The system has been designed on MATLAB/SIMULINK

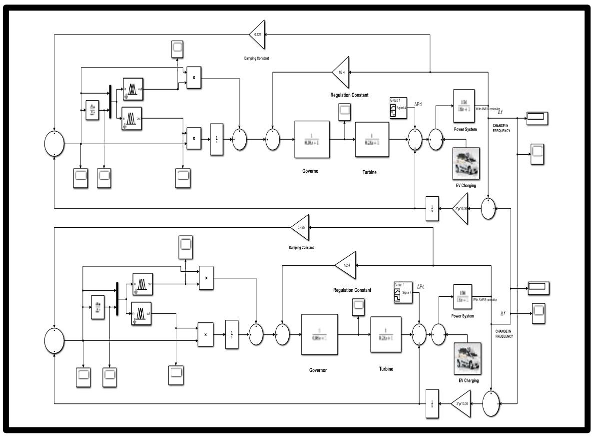

Fig.6 ANFIS Controlled LFC Model

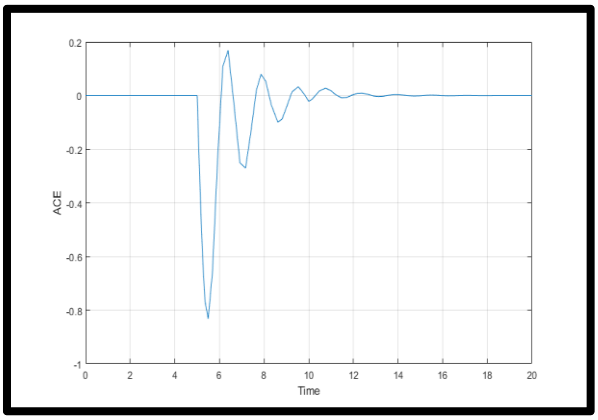

Fig.7 ACE for ANFIS Controller

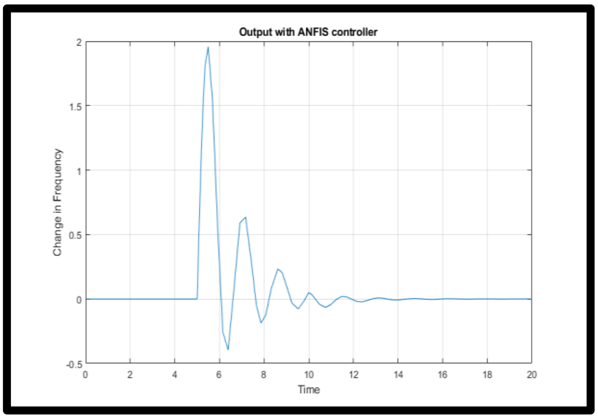

Fig.8 Change in Frequency for for ANFIS Controller

Table.1 Summary of Results

Parameter	**Value**
Rise Time:	1.3832e-05 sec
Settling Time:	11.0145 sec
Settling Min:	-0.3966 Hz
Settling Max:	0.6361 Hz
Overshoot:	6.6417e+05
Undershoot:	3.2790e+06
Peak:	1.9579 Hz
Peak Time:	5.4959 sec

V. Conclusion:

For Electric Vehicles, Load Frequency Control (LFC) is used to regulate and control the output frequency signal of the electrically generated power within an area in response to changes in system loads. This work discusses the effect of electric vehicles on the load frequency deviation. This project shows a case study of designing a controller that can withstand optimal results in a two-area power system when the input parameters of the system are changed. Two methods of Load Frequency Control were studied considering an isolated power system.

The performance of the controller's understudy is tested and validated using MATLAB/SIMULINK tools. On comparison, it was found that ANFIS has minimum settling time, and minimum percentage overshoot out of the two.

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.

By adding generation control and governor dead band into the system the system will look more realistic and nonlinear

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