Development of an Intelligent Speed Controller for a Hybrid Electrical Vehicle

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Abstract: The Hybrid Electrical Vehicle (HEV) emerges as the new era solution for the pollution that is caused by conventional vehicles and battery shortage issue in electrical vehicles. This technology has got higher demands in the recent years. Due to increase in demand and manufacturers competitiveness, there is need of better control and management system for HEV for efficient and optimal control. Controller design plays a vital role in this regard as all the control actions are dependent upon it. Therefore, in this research, intelligent controller is designed that is based on Artificial Neural Network technique. Which shows better and effective results for controlling speed of HEV, making environment ecofriendly and eliminating all battery shortage issues.

Keywords: *Artificial Neural Network, Control, Hybrid Electrical Vehicle, Management, Speed Controller*

1. Introduction

Advancement in hybrid electrical vehicle technology has increased due to expansion in greenhouse effect and global warming along with decrease in resources and energy[1]. It is a solution to make pollution free, eco-friendly environment in which minimal fuel usage makes it economic for daily use. Therefore, Hybrid cars are used massively and recognized worldwide for their dual nature and combined ICE and electrical motor properties. This energy management system of both the engines for producing optimal control in hybrid electrical vehicles [2] makes it efficient over electrical and conventional vehicles. Minimizing overall emission and fuel consumption[3].

Optimum Speed Control and energy management is the main problem in HEV for balancing electric motor and ICE powered engine. For that purpose, powerful controllers are essentially required for exceptional management and control. Energy management and rule base strategy was developed and presented [4] as HEV concept was gaining name around the world. Dynamic programming and model based approach was the old approach used for improving HEV fuel consumption[5][6][7]. Since Beginning, conventional PID, PI, and PD controllers have been used [8] as a basic control technique for controlling nonlinear HEV. Along with PID, other linear optimization techniques have also been used in HEV for speed control including LQR, pole placement, and state observer based controller[9], [10]. Two PI+PI cascade controllers were used for HEV efficient performance and system management[11]. But we all are well aware about their limitations and drawbacks. Nonlinear HEV cannot be completely optimized with linear control approaches. For more efficient control, Artificial Intelligent techniques such as neural network [12], adaptive Neural network [13], particle swarm optimization gravity search algorithm [14], fuzzy logic [15], [16], [17], [18] genetic fuzzy [19] and genetic algorithm [20] were used for tuning P, I and D parameters in PID controller for HEV speed control[21]. Also, Several works were done on different fuzzy tuned PID controllers[22]. Improved self-tuning fuzzy proportional–integral–derivative (ISTF PID), advanced fuzzy nonadaptive PID (AF-NA-PID), and advanced fuzzy adaptive PID (AF-A-PID) controller were used and compared [23], [24] with each other for discovering better control technique to control HEVs throttle position. ANN approach was the one to bring somewhat better performance in controller design in comparison with all the other approaches. ANN can conveniently learn from its environment and model input output relationships of a complex nonlinear system. Therefore for HEV management and control, optimizing and working on ANN controller design is the main objective of this paper.

2. Introduction to HEVs

Hybrid Electrical vehicles (HEVs) are the vehicles that uses internal combustion engine in addition to the battery and motor where both work together effectively to achieve better efficiency than non-hybrids vehicle. Petrol engine and Electric engine divides their power in such a way that when car is driving at lower speeds in city, electric engine and battery power is utilized. While at higher speed on highways, petrol Engine powers the vehicle, making it economic and affordable. HEVs are also environmental friendly as it has reduced CO_2 emissions and better gas mileage. It has efficient Fuel consumption and a lot of money are saved as less petrol is utilized due to dual engine properties. When extra fuel is burned in gasoline car (in traffic), no fuel is used in hybrid electrical cars as power is supplied by battery engine only. Moreover dual powertrains drive the wheels, providing support to each other. When in case if one stop working there is always an alternate power source as a backup to keep the vehicle going which is not possible in traditional or electric cars as they are driven by single powertrain.

Hybrid electrical vehicle has advanced features like Regenerative braking system, power assist and automatic

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start stop to make it powerful over all the other vehicles. In regenerative braking system, battery is recharged every single time when brakes are applied eliminating battery shortage issue. In power assist, additional power is provided by the electric engine for passing hills and other power consuming actions. In automatic start stop, petrol engine is automatically turned off when vehicle is idle like on signals while battery power is used for air conditioner and other accessories. This intelligent dual engine control of hybrid electrical vehicle makes it a lot efficient and better than other cars.

HEVs are classified into Series, Parallel and Series Parallel Hybrid vehicles. In this paper, intelligent controller for Series Hybrid Vehicle is proposed in which gasoline engines drives the generator which charges battery and provides power to the motor that is connected to the drive shaft.

3. Introduction to Artificial Neural Network

Artificial Neural Network (ANN) is a computational tool with flexible and self-adaptive nature to control complex and nonlinear properties of a system. ANN is inspired by biological neural network from human brain and mimics the function performed by it. Neural Network is based upon neuron and it is approximated that human brain contains about 150 billion neurons inter-connected together to build up the network making it complex and structured. In ANN, one neuron is connected to the other with different weights and information which is then distributed for learning during training.

Artificial Neural Network have ability to learn from its experience and makes decisions accordingly when faced to similar environment. Artificial Neural Network are multitasking and have ability to perform more than one function on same duration. ANN is widely used in control applications which include processes like nonlinearity removal, optimization and identification with different parameters in complicated operations.

In this paper feedforward neural network controllers are proposed. In feedforward neural network, neurons are arranged in layers and each layer is connected to the next layer allowing information to transfer in forward direction only. Information comes at input layer and it is transferred at hidden layers until it reaches at the output layer.

4. Simulation Model

The simulation model used in this paper has been taken from literature which shows the block diagram of a possible cascade control scheme for an HEV driven by a dc motor. Figure 1 shows the bock diagram of the simulation model that is taken from [11] along with its numerical values. The model has been thoroughly analyzed and investigated by Nise [25]. Preitl and Bauer[11] used two conventional PI controllers and simulated in MATLAB SIMULINK for controlling speed and current of a hybrid electrical vehicle but those controllers were linear controllers therefore we are replacing those controllers with neural network based controllers. The model is shown in Figure 1 which is a cascade control scheme for the HEV driven by a dc motor. G_{c1} and G_{c2} are the speed controller and torque controller respectively. The input and output of the model are reference speed and actual speed of the vehicle respectively.

In this paper, a feedforward neural network is developed to replace the speed controller i.e. G_c1. Because of nonlinear nature of neural network controllers, it is expected that better performance can be achieved. The feedforward neural networks are trained by using the supervised learning strategy. The weights are calculated by using the error back-propagation learning algorithm. The developed neural network is a three layer network: input, hidden and output layer, as shown in Figure 2.

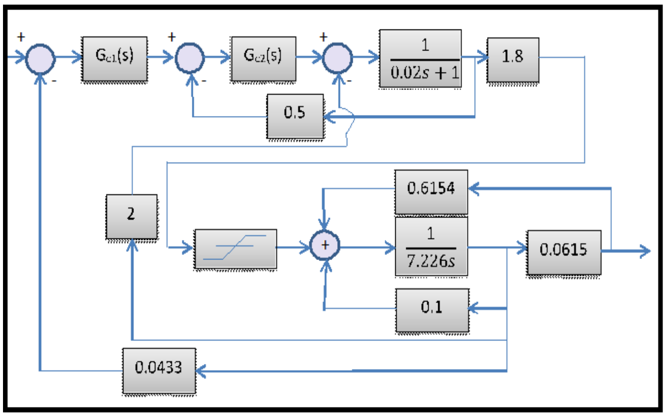

Figure.1. Cascade Control Scheme for the Hybrid Vehicle

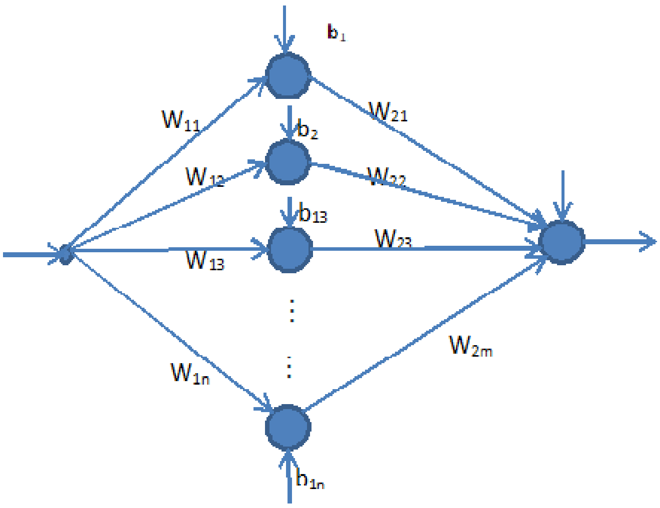

Figure.2. Proposed Neural Network Controller

5. Results and Discussion

The first step in the development of a neuro controller is to generate data for training. For this purpose, we generated data by using the PI controller of reference [11]. Neural network toolbox was used for training of the network. Figure 3 below shows the successful training of NN speed controller model and its comparison with original speed controller where dotted blue lines represents original controller response and solid red lines represents trained NN speed controller response. Similar responses of original and trained NN model shows successfulness of neural network technique for this particular application.

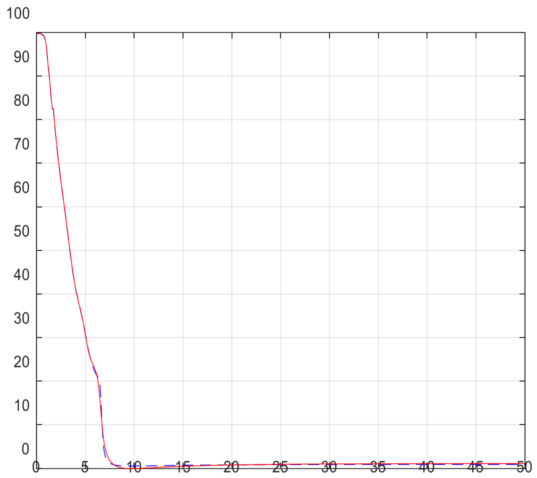

Figure.3. Trained Neural Network Model

Architecture of proposed neural network speed controller is shown in figure 4. It can be seen clearly that model is based on feedforward neural network with 3 functioning layers. Through supervised learning, neurons at input, hidden and output layers are trained. Its input and output layer consist of single neuron whereas hidden layer consist of 5 neurons. Neurons in hidden layer uses sigmoid transfer function and neurons in output layer uses linear transfer function. Biases and weights for each neuron are given as shown in figure 4. Where w1 and b1 represents input weights and biases and w2 and b2 represents output weights and biases.

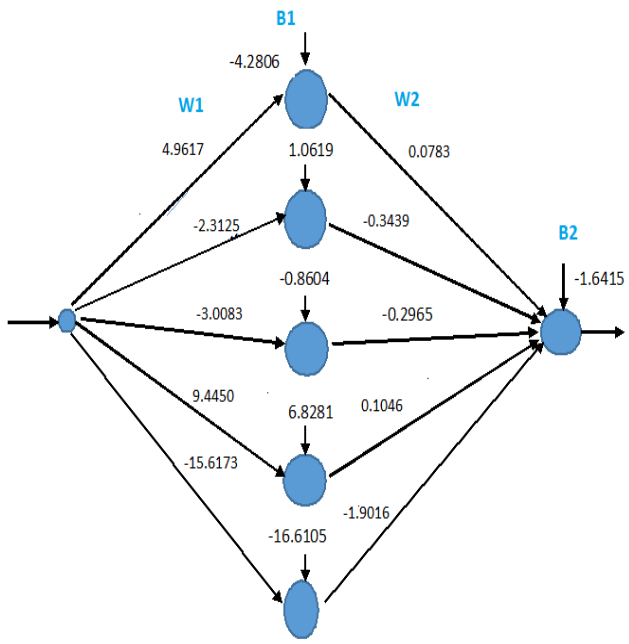

Figure.4. Architecture of proposed NN speed controller

Neural Network training tool is shown in figure 5 which shows details and performance specifications about the trained NN speed controller, taken from MATLAB. In training process of NN model, 50 iterations were done for successful results of NN speed controller as shown below.

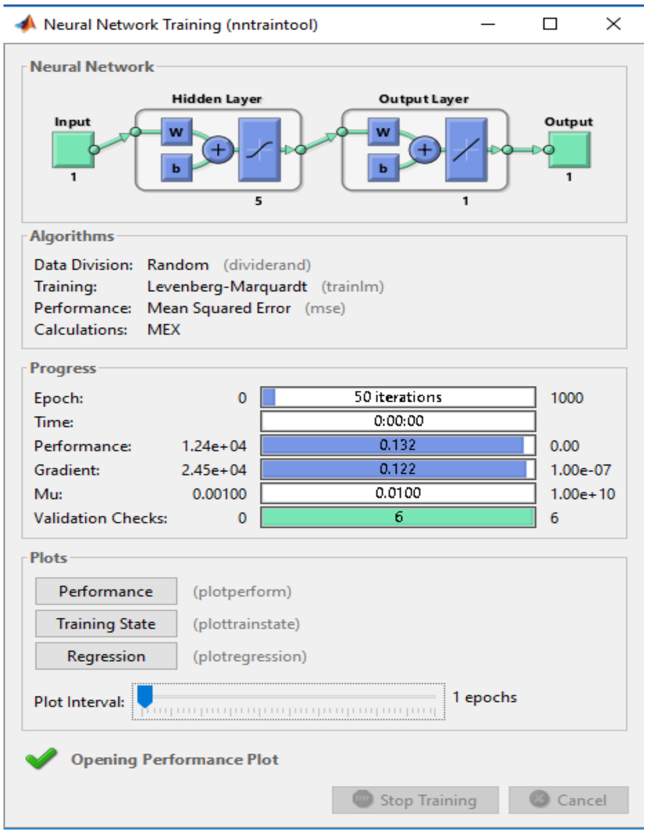

Figure.5. Training Tool for NN Speed Controller

Performance graph of proposed neural network speed controller is shown in figure 6 which shows best validation performance that is 0.14172 at 44 epoch. All the performance specifications in graph seems ideal and shows stability from which we can conclude that the proposed NN controller is ideal for the application in HEV.

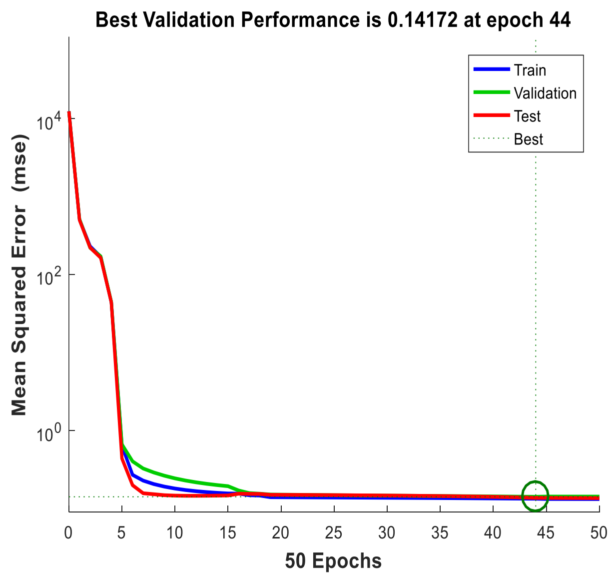

Figure.6. Performance Graph of NN Speed Controller

Figure 7 below describes the regression plot of proposed neural network speed controller showing data points of training, validation and test performance specifications in alignment which displays data points of successfully trained NN speed controller as shown.

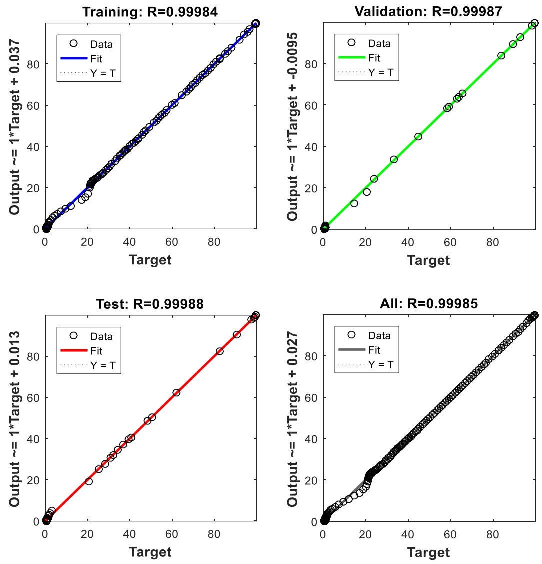

Figure.7. Regression plot of NN speed controller

After successful training of proposed NN speed controller, neural network speed controller is replaced with conventional PI speed controller in the block diagram to get overall system response and proposed NN controller response for determining the efficiency of proposed controller for HEV application. Figure 8 shows NN speed controller which is replaced in block diagram with conventional PI speed controller.

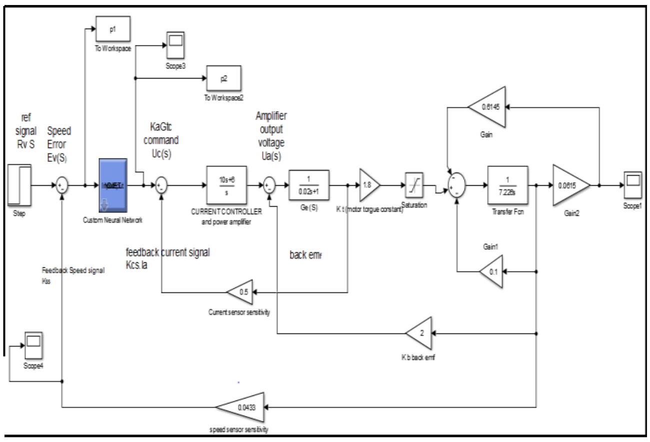

Figure.8. Neural Network Speed Controller

Output of the neural network speed controller is shown in figure 9 when it is replaced with conventional speed controller after successful training. The output response of NN speed controller is quicker than the conventional speed controller. From model shown below it can be viewed that Initial speed was 100 m/s and within 1.5 seconds it settles to 0 m/s. Rpm we get from proposed NN speed controller is 1.66 which is ideal rpm for optimal control and efficient management of HEV.

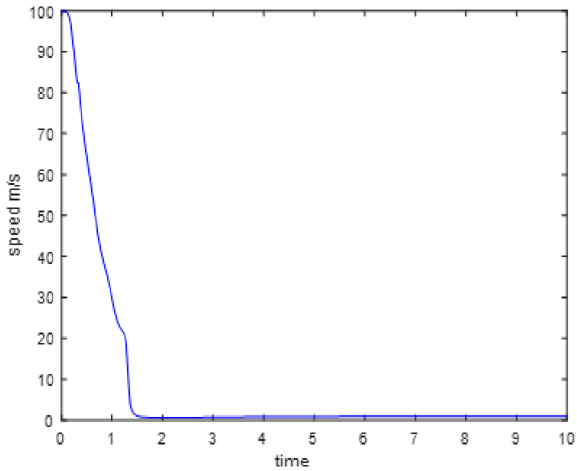

Figure.9. Proposed NN Speed Controller Output

Figure 10 shows the overall system output when proposed neural network speed controller is replaced with conventional speed controller in HEV model. System response from NN speed controller is better and efficient than the conventional speed controller which does not have any overshoots in transient response and has stable steady state response as shown in the figure below.

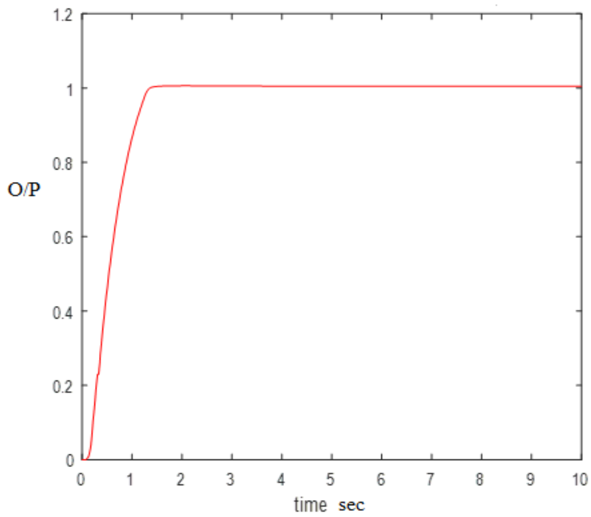

Figure.10. System Response of Neural Network Speed Controller

Figure 11 shows results obtained through neural network speed controller which has been compared with the conventional PI speed controller. In this figure, solid blue line represents the response of the conventional PI speed controller and dotted red lines shows the neural network speed controller response. It can be seen that the proposed neural network controller response does not have any overshoot, however PI controller has overshoot. The proposed controller and PI controller both have same response but the transient response of NN speed controller is better and efficient than the conventional PI speed controller as shown below.

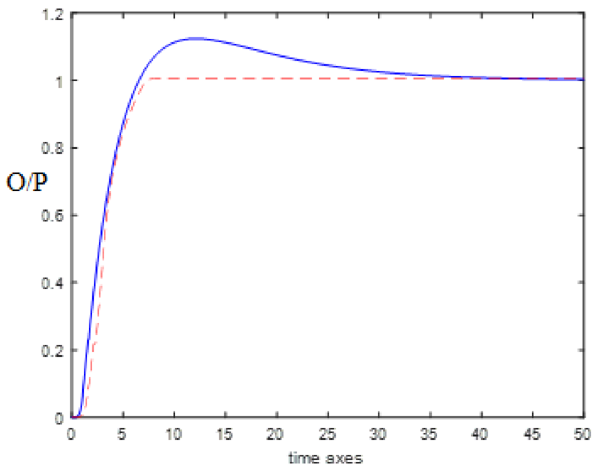

Figure.11. Comparison of Neural Network and PI controllers

6. Conclusion

This paper, proposes a neural network as a speed controller for a hybrid electrical vehicle. A mathematical model has been taken from the literature and a conventional PI controller has been used to generate data for training. Simulation results show that the proposed neural network based speed controller shows better transient behavior in terms of the overshoot. As its response is better than the PI controller, therefore it gives optimal and efficient speed control and management of hybrid electrical vehicle, making environment clean and reducing pollution from the city with efficient controller design. Moreover this is preliminary work. Further investigations are underway to develop a neural network based cascade control system with speed and current control schemes for optimal management and control of HEV.

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