International Journal of Computing and Network Technology

Speed Control of Hybrid Electric Vehicle Using Artificial Intelligence Techniques

Japjeet Kaur, Prerna Gaur, Piyush Saxena and Vikas Kumar

Department of Instrumentation of Control Engineering, Netaji Subhas Institute of Technology, New Delhi, India

E-mail: japjeet_shiney@yahoo.co.in, prernagaur@yahoo.com, piyushsaxena@yahoo.com sainivika@gmail.com

Received: 24 Aug. 2013, Revised: 28 Oct. 2013, Accepted: 30 Oct. 2013, Published: 1 Jan. 2014

Abstract: Growing concerns regarding toxic CO_x and NO_x emissions caused by the vehicles and the scarcity of over-exploited non-renewable resources that led the automobile industry to look out for a more energy efficient energy consumption is the main reason behind the development of Hybrid Electric Vehicles (HEVs). This paper comprises of artificial intelligence techniques employed to achieve smooth speed tracking performance in nonlinear HEVs. Techniques like fuzzy logic, neural network and genetic algorithm have been applied to tune and optimize the parameters of Proportional-Integral-Derivative (PID) controller.

Keywords: Hybrid Electric Vehicle; Artificial Intelligence techniques; PID controller; optimization; Fuzzy logic; Neural Networks; Genetic Algorithm.

I. INTRODUCTION

Surprisingly, the concept of a hybrid electric vehicle is almost as old as the automobile itself. The primary purpose, however, was not so much to lower the fuel consumption but rather to assist the ICE to provide an acceptable level of performance. But this highly developed automobile industry has resulted in the deterioration in air quality, global warming and decrease in non-replenishable petroleum resources. More and more stringent emissions and fuel consumption regulations have stimulated an interest in the development of safe, clean, and high-efficiency transportation. In recent decades, the research and development activities related to transportation have emphasized that the hybrid is the ideal transition from the all-petroleum vehicle to the all-electric vehicle.

The pioneering authors are actively working to improve the fuel economy and vehicle performance so as to achieve high efficiency, ruggedness, small sizes, and low costs in power converters and electric machines, as well as in associated electronics [1]. The performance of HEV depends primarily on the applied automation system but the conventional controllers designed haven't proved to be competent due to imprecise input output relation and unknown external disturbances. Many controllers such as LQR controller, state feedback controller, observer based controller have been designed in near past [2-3].

By controlling the servo motor which in turn is controlling the throttle position to have smooth torque, the speed of the HEVs can be controlled. Some other authors have proposed different control technique for electric vehicle [5].

This work comprises the tuning of a conventional PID controller used to optimize the speed of the HEV. There are a number of tuning methods for classical controllers, such as, the Ziegler-Nichols methods, pole placement procedures, the quarter decay ratio method, performance indices (ISE, IAE, ITAE, and ITSE) based optimization. Nowadays, all these methods are usually employed to a limited class of problems as they possess some drawback. In this paper, we propose an automatic tuning method for a PID controller by means of artificial intelligence techniques: Fuzzy Logic, Artificial Neural network and Genetic Algorithm (GA).

This paper is organized as follows: in section two the details of the model undertaken are posed; section three presents the control strategy used; section four shows the results; and hence conclusions are drawn in section five.

II. SYSTEM DETAILS

Fig. 1 shows a schematic diagram of the electronic throttle control using a DC servo motor. The dynamics of the vehicle are taken as configuration of leader-follower [2], [6] given below and the hence designed Simulink model is shown in Fig. 2.

Given below are the assumptions made:

1. Gravity induced force (f_g) is 30% of weight of vehicle.
2. Engine time constant (τ_f) is taken as 0.2s that generally ranges from 0.1 to 1sec.

The value of all other parameters is shown in Table I.

A. Open Loop Stability Analysis

The transfer function is obtained from given system dynamics and hence state equation is obtained. [2]

Transfer function:

$$\frac{V(s)}{\theta(s)} = \frac{829000}{s(s+5)}$$

State space variable:

$$A = \begin{bmatrix} 0 & 1 \\ 0 & -5 \end{bmatrix}, \quad B = \begin{bmatrix} 0 \\ 829000 \end{bmatrix}$$

$$C = [1 \quad 0\,], \quad D = [\,0\,]$$

The characteristic equations of system is $|\lambda I - A| = 0$, whence we get the eigenvalues as $\lambda 1 = 0$, $\lambda 2 = -5$. The system is found controllable and observable, as the order of matrix M and N is equal to rank = 1; $M = 829000 \times \begin{bmatrix} 0 & 1 \\ 1 & -5 \end{bmatrix}$, $N = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$.

III. CONTROL STRATEGIES

A. PID Controller

Proportional-integral-derivative control is a feedback controller involving three separate constant parameters, the proportional, the integral and derivative values, denoted *P*, *I*, and *D*, therefore sometimes called three-term control: The Simulink model of vehicle controlled by PID controller is shown in Fig. 3.

By combining the advantages like quicker response time (due to P-only control), along with the decreased/zero offset (due to I-only control) and prediction of disturbances to the system (due to D-control) minimizes the error between some user-defined set point and the measured process variable. The actuating signal for the PID controller and the transfer function are given in (3) and (4)

$$e_a(t) = e(t) + K_d \frac{de(t)}{dt} + K_i \int e(t)\, dt \qquad (3)$$

$$C(s) = K_p + \frac{K_i}{s} + K_d s = K_p\left(1 + \frac{1}{T_i s} + T_d s\right) \qquad (4)$$

Where: K_p = Proportional Gain, K_i = Integral Gain, T_i = ResetTime $=K_p/K_i$, K_d =Derivative gain, T_d =Rate time or derivative time $=K_d/K_p$.

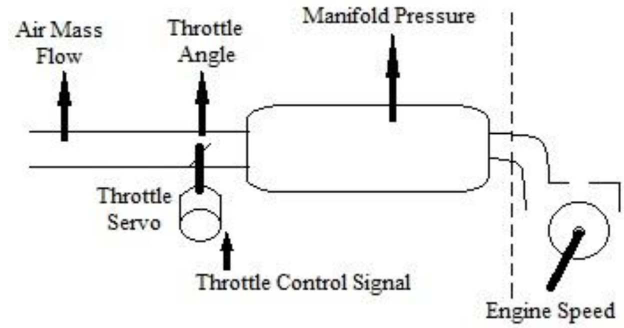

Figure 1. Schematic diagram of electronic throttle control [2]

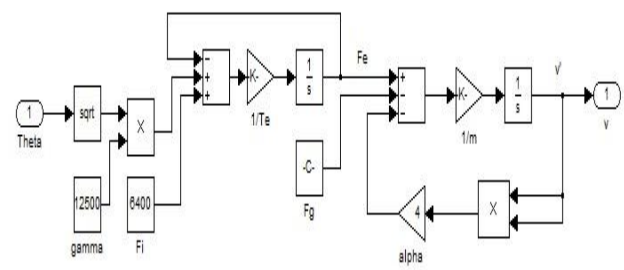

Figure 2. Simulink model of Hybrid Electric Vehicle

TABLE I. NUMERICAL VALUES OF THE PARAMETERS

Constant	Notation	Value (SI Unit)
Mass of Vehicle	M	1000 Kg
Aerodynamic Drag Coefficient	α	4 $N/(m/s)^2$
Engine Force Coefficient	γ	12500 N
Engine Idle Force	f_i	6400 N

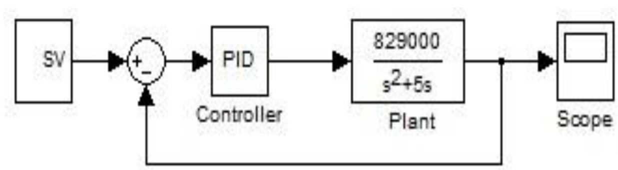

Figure 3. Model with PID Controller

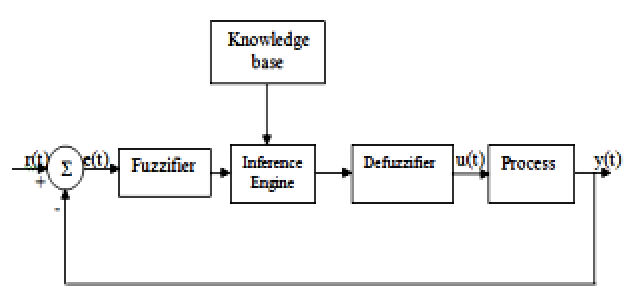

Figure 4. Block diagram of fuzzy controller

B. Fuzzy Logic

The first seminal paper of "Fuzzy Logic" was given by Prof. Lotfi Zadeh in 1965 on Sets the Foundation of the Fuzzy Set theory. Fuzzy systems are knowledge/rule based systems resembling human decision making with an ability to generate precise solutions from certain or approximate information. While other approaches require accurate equations to model real world behaviours; fuzzy logic can accommodate the ambiguities of real-world human language and logic by providing an intuitive method for describing systems in human terms and converting it into effective models.

Being non-linear in nature, it is more difficult to set the gains in fuzzy logic controller (FLC) shown in Fig. 4, as compared to PID controllers. In this paper, two types of configurations are applied, mainly, fuzzy PD and fuzzy PD+I. The Mamdani based FLC has two-input (e, ce), divided into seven states and one-output (u). The control performance depends on the adopted rule base, so, 7 inputs & 7 output membership functions are described in 49 Fuzzy–if-then rules given in Table II.

Note that states are represented as abbreviations like “NS” for “negative small” and so on as it helps to keep the linguistic descriptions short yet precise.

Fig.5 shows Simulink model of HEV with fuzzy PD Controller and Fig.6 shows the simulink model of fuzzy PD block. Similarly, Fig. 7 and 8 shows the model with fuzzy PD+I controller and its block respectively. It gives the better performance in comparison to conventional PID controller and improves the performance index such as maximum overshoot, settling time, and study state error.

C. Neutral Network

Neural networks, with their remarkable ability to derive meaning from complicated or imprecise data, are good pattern recognition engines that comprise collections of identical mathematical models emulating the behaviour of biological nervous systems. ANN’s have shown that they are capable of identifying complex nonlinear systems and are well suited for generating the complex internal mapping from inputs to control actions by detecting trends that are too complex to be noticed by either humans or other computer techniques.

Fig. 9 shows proposed neural network controller, which was trained to replace the conventional PID speed controller. The neural network controller which is static type has replaced PID controller, thus simplifying the control implementation and reducing the development time. In this paper, a 3-layer back-propagation based feed-forward artificial neural network controller is designed. All nodes of specific layer are connected by weights that represent the strength of the connection.

The designed neural network controller hence obtained is trained using the target values to find out the desired mean square error. During training, the output signal is compared to the desired output signal, and the weights are adjusted each time by the back-propagation algorithm. Fig. 10 shows the Simulink model of HEV with ANN controller.

D. Genetic Algorithm

Genetic Algorithm, formerly introduced by John Holland in the 60s, is an adaptive heuristic, stochastic global search method inspired by Darwinian evolutionary ideas. Operating on the principle of the survival of the fittest, they intelligently exploit a population of potential solutions within a defined search space and provide alternative methods to solve real-world high-dimensional, nonlinear problems.

TABLE II. FUZZY RULE BASE

(ce) \ (e)	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NB	NB	NM	ZE
NM	NB	NB	NB	NB	NM	ZE	PM
NS	NB	NB	NB	NM	ZE	PM	PB
ZE	NB	NB	NB	ZE	PM	PB	PB
PS	NB	NM	ZE	PM	PB	PB	PB
PM	NM	ZE	PM	PB	PB	PB	PB
PB	ZE	PM	PB	PB	PB	PB	PB

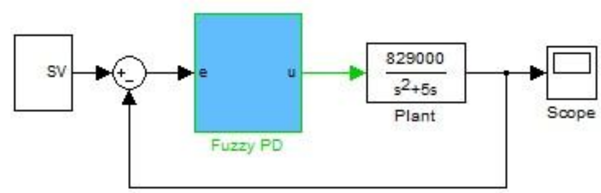

Figure 5. Simulink model of HEV with Fuzzy PD controller

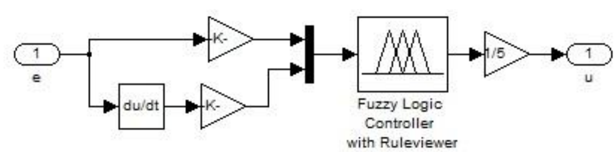

Figure 6. Fuzzy PD Block

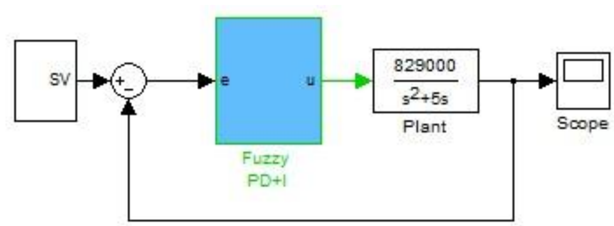

Figure 7. Simulink model of HEV with Fuzzy PD+I controller

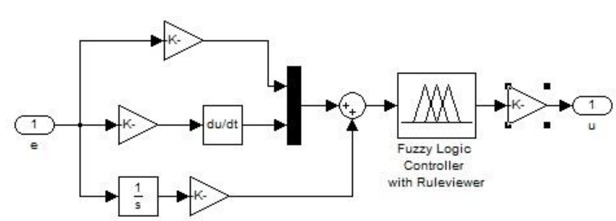

Figure 8. Fuzzy PD+I Block

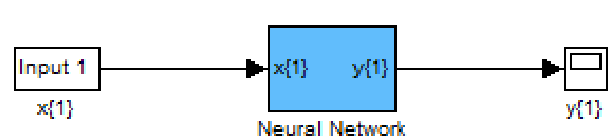

Figure 9. Generated proposed ANN model to replace PID controller

A GA based optimization process generates a random set of approximations (binary or decimal strings) termed as population by selecting individuals according to their fitness levels. Based on nature-inspired operators (reproduction, crossover, mutation etc.) new individuals (better suited) are created at each generation. The fitness is usually the value of the objective function in the optimization problem being solved. The procedure then stops when a pre-defined number of generations is reached or before that if a very good solution is found.

This parallel, global search procedure does not require any derivative information or other auxiliary knowledge other than the fitness levels and the objective. In this paper, the objective is smooth throttle movement and quickest settling time that will minimize the error of the controlled system. The fitness function provides a link to the application wherein a suitable weighted function is defined that considers each constraint to analyse the performance of each chromosome in the population. The objective function includes the way the parameters are to be minimized. This means that an optimal solution is found to satisfy a priori defined fitness function.

1) Selection: The selection operator primarily determines the eligibility of the solutions based on the fitness evaluation that will later generate offsprings of future populations. The chances for recombination and generation of offspring are higher for the individuals having small fitness function value, if the optimization problem is a minimization one. In this work the Uniform Selection is employed to implement the selection operator.

Reproduction cannot create new and better strings. This improvement may be achieved by Crossover and to a lesser extent by Mutation.

2) Crossover: This is a genetic operator that combines (mates) two individuals (parents) to produce a new one (offspring) according to a user-definable crossover probability. It selects random individuals from mating pool and the gene information between them is exchanged (according to defined crossover ratio) such that it takes the best characteristics from each of the parents.

3) Mutation: The mutation operator ensures that genetic diversity is maintained in the mating pool by removing or reinserting a critical feature (genetic information) from a population and so it is considered as a secondary mechanism of GA adaption. New individuals are generated by random modification of the value of a string position (gene) that will converge the search algorithm to a global solution.

The goal of the system is to design a controller that ensures optimal speed tracking performance. The code is written using Mfile in MATLAB. The integral gains of the PID controller are optimized based on the Genetic Algorithm. GA is used to calculate the optimum value of the variables based on the best dynamic performance and a domain search of the variable.

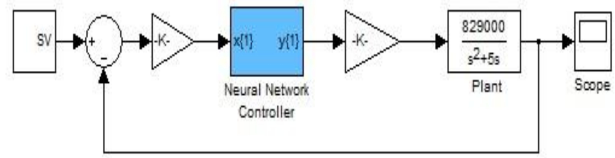

Figure 10. Simulink model of HEV with ANN controller

TABLE III. PARAMETERS OF GA

Operators	Values/Parameters Assigned
Population Size	20
Selection	Uniform
Crossover	Arithmetic
Objective Function	Mean Square Error

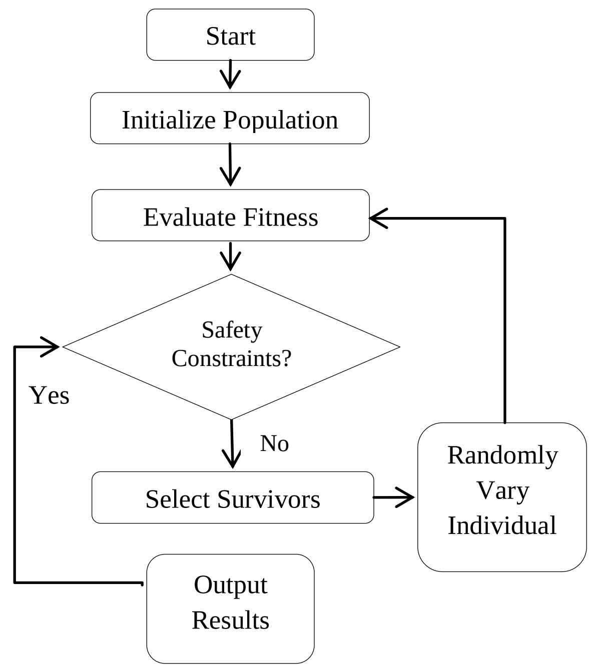

Figure 11. Flow Chart for the operation of GA control

GA finds the values of K_p, K_i and K_d of the PID controller based on chosen operators, to achieve better dynamic performance of the overall system. These values of gains lead to the optimum value of gains for which the system achieves the desired values by improving the rising time and oscillations. The main aspects of the proposed GA approach for optimizing the gains of PID controller, and the flowchart procedure for the GA optimization process is shown in Fig. 11. Parameters considered in GA are shown in Table III.

IV. SIMULATION RESULTS AND DISCUSSIONS

In this section the results obtained from the open loop system without controller and closed loop system with controller are presented. The response of the system with controllers such as PID and GA tuned PID are presented and compared. Fig. 12 shows the Open loop step response that shows the system is unstable as it is not converging.

Fig. 13 shows the response with PID Controller. Here PID controller is tuned by using both Hand-tuning rule and Ziegler-Nichols method that gives 46.7% and 15.6% Max overshoot respectively. Tuning by hand tuning rule gives better performance. Fig. 13 also shows the vehicle response for GA-tuned PID, which is an improvement over the former one.

Fig. 14 shows the response with ANN controller, where it takes longer time for controlling the vehicle. Fig. 15 and 16 shows the fuzzy PD and fuzzy PD+I controller response, where both reduces the overshoot and settling time as well.

Fig. 17 shows the combined response of all controllers for first 5 seconds to make the comparison among them and Fig. 18 shows the enlarged view of Fig. 17. The performance index shown in Table IV is made by using Fig. 18.

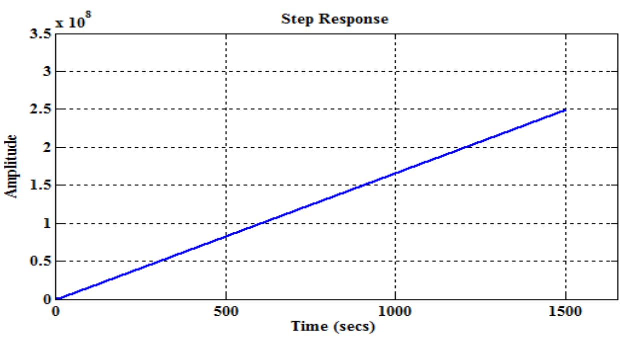

Figure 12. Open Loop Step Response

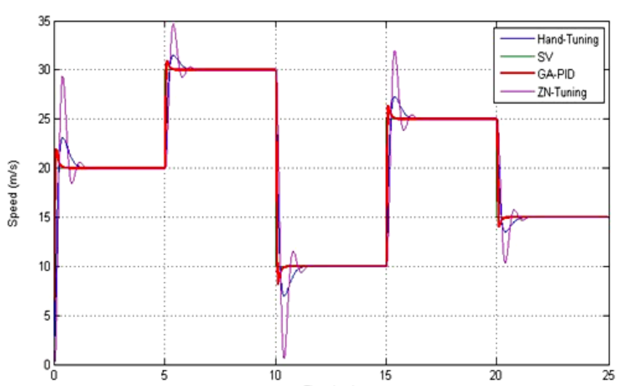

Figure 13. Vehicle response of Conventional PID and GA-tuned PID controller

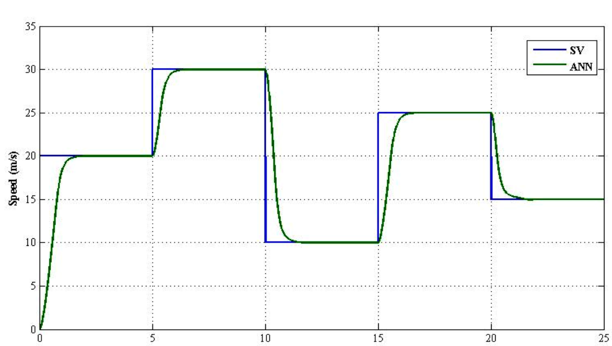

Figure 14. Vehicle response with ANN conttroller

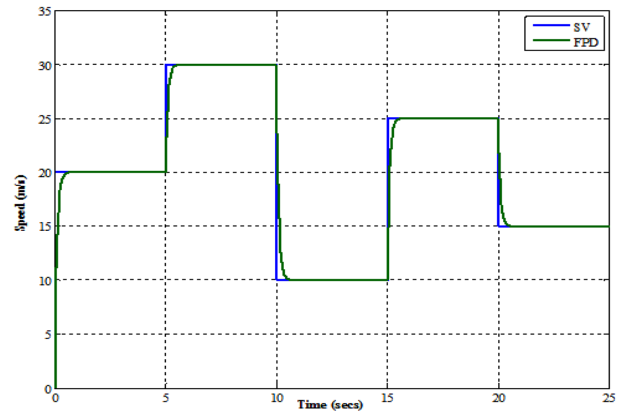

Figure 15. Vehicle response with Fuzzy PD controller

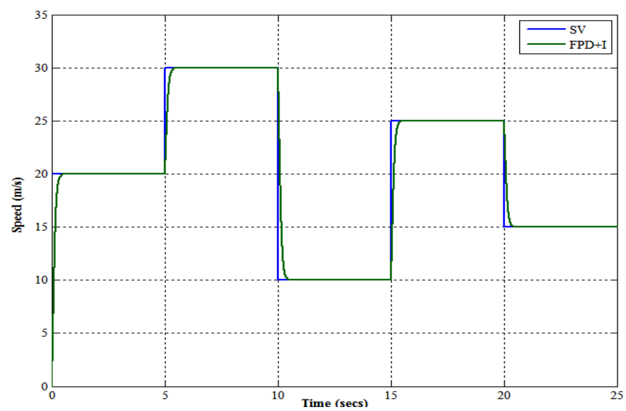

Figure 16. Vehicle response with Fuzzy PD+I controller

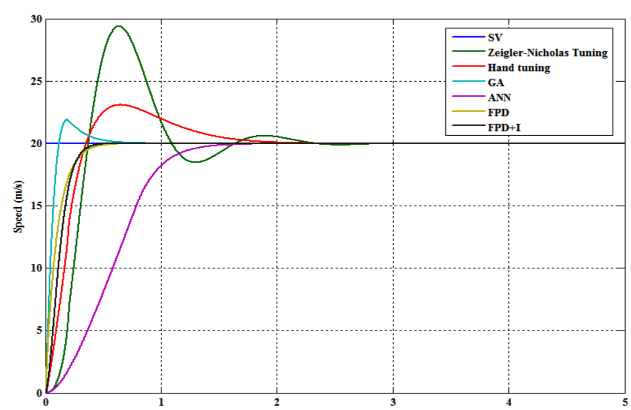

Figure 17. Combined Vehicle Response

On the basis of Fig. 18 that shows the enlarged view of Fig. 17 and Table IV, the Fuzzy PD+I controller response has got least max. overshoot, i.e. 0%. Hence fuzzy PD++I controller gives better performance index in comparison with PID.

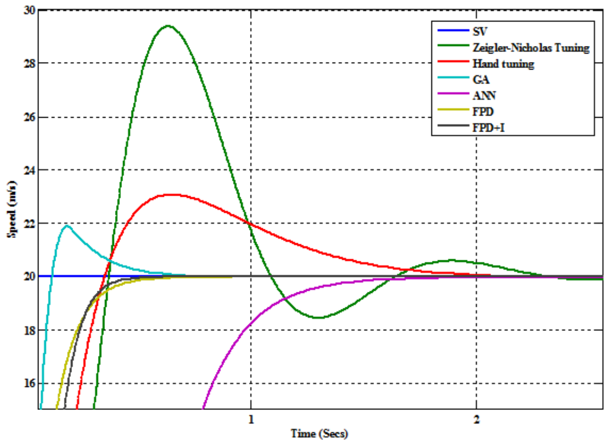

Figure 18. Combined Vehicle response (enlarged)

TABLE IV. PERFORMANCE INDICES

Controllers	% Max Overshoot	Settling Time (s)	Rise Time (s)
PID	15.6	0.79	0.19
GA-PID	9.5	0.27	0.05
ANN	~0	1.29	0.765
FPD	~0	0.392	0.218
FPD+I	~0	0.352	0.205

V. CONCLUSION

A comparative analysis of all the controllers applied to control the speed of nonlinear hybrid electrical vehicle, vividly shows that fuzzy PD+I controller gives better performance result. Although the settling time and rise time are more than that of GA but since our design objective is to have smooth throttle control so as to have reduced torque ripples that will in turn reduce the current and overall operating cost and increase battery life. Also the battery operation of such vehicles will be optimal. Vehicle drive train efficiency may be improved and the fuel efficiency of HEV may also be optimized.

REFERENCES

[1] Ali Emadi, Young Joo Lee, and Kaushik Rajashekara, “Power Electronics and Motor Drives in Electric, Hybrid Electric, and Plug-In Hybrid Electric Vehicles”, *IEEE Transactions on Industrial Electronics*, Vol. 55, No. 6, pp. 2237-2245, June. 2008

[2] A. K.Yadav, P. Gaur, S. K. Jha, J. R. P. Gupta, and A. P. Mittal, “Optimal speed control of Hybrid Electric Vehicles”, *Journal of Power Electronics*, Vol. 11, No. 4, pp. 393-400, July 2011.

[3] Japjeet K., P. Gaur, P. Saxena, “Genetic algorithm based speed control of Hybrid Electric Vehicle”, *IEEE Conference on Contemporary Computing*, pp. 65-69, August 2013.

[4] X. Liu, Q. Huang, Y. Chen, and J. Li, “Nonlinear modelling and optimal controller design for Radar Servo System”, Third International Symposium on Intelligent Information Technology Application, pp. 327-330, 2009.

[5] A. Varsek, T. Urbantit & B. Fillipit, “Genetic algorithms in controller design and tuning*”, IEEE Transactions Systems Man and Cybernetics*, Vol. 23, No. 5, pp. 1330–1339, 1993.

[6] K. M. Junaid and S. Wang, “Automatic Cruise control modelling-a lattice PWL approximation approach*”, Proc. of the IEEE ITSC*, pp. 1370-1375, Sep. 2006.

[7] Karen L. Butler, Mehrdad Ehsani, Preyas Kamath, “A Matlab-Based Modeling and Simulation Package for Electric and Hybrid Electric Vehicle Design”, *IEEE Transactions on Vehicular Technology*, Vol. 48, No. 6, pp. 1770-1778 Nov. 1999.

[8] L. Feiqiang, W. Jun, L. Zhaodu, “On the vehicle stability control for Electric Vehicle based on control allocation,” *IEEE Vehicle Power and Propulsion Conference (VPPC)*, pp. 1-5, 2008.

[9] M. Namazov, “DC motor position control using Fuzzy proportional-derivative controllers with different defuzzification methods,” *Turkish Journal of Fuzzy Systems*, An Official Journal of Turkish Fuzzy Systems Association, Vol. 1, No. 1, pp. 36-54, 2010.

[10] S. Omatu, M. Yoshioka, and T. Kosaka, “PID Control of Speed and Torque of Electric Vehicle”, *Third International Conference on Advanced Engineering Computing and Applications in Sciences*, pp. 157-162, 2009.

[11] Gadoue, S.M.; Giaouris, D.; Finch, J.W., "Sensorless control of Induction Motor Drives at very low and zero speeds using Neural Network Flux Observers," *Industrial Electronics, IEEE Transactions on* , vol.56, no.8, pp.3029,3039, Aug. 2009

[12] Atri, Amit, and Md Ilyas. "Speed control of DC motor using Neural Network configuration." *International Journal of Advanced Research in Computer Science and Software Engineering* Vol.2, No. 5, pp. 209-212, May 2012

[13] Sumathi, S., Hamsapriya, T., & Surekha, P. “Evolutionary Intelligence: An introduction to theory and applications with Matlab”, Springer, 2008

[14] Wei Liu, “Introduction to Hybrid Vehicle system modelling and control”, Wiley, 2013.

Japjeet Kaur received her B.Tech Degree in 2010 from P. D. M. College of Engineering, M. D. University, Haryana and M.Tech degree in Instrumentation and Control Engineering from Netaji Subhas Institute of Technology, Delhi University in 2013.

Prerna Gaur received her B.Tech and M.E in 1988 and 1996 from G.B. Pant College of Technology, Uttranchal, India and Delhi College of Engineering, Delhi University, respectively. She is PhD in the field of Motion Control of PMSM. She joined the industry in 1989 and Delhi College of Engineering as a Lecturer in 1994. She is an Associate Professor in the Instrument and Control Engineering Division at Netaji Subhas Institute of Technology, Delhi. She is a Life Member of the Indian Society for Technical Education (ISTE) and Senior Member of Institute of Electrical and Electronics Engineers (IEEE). Her research interests include Power Electronics, Electric Drives, Artificial Intelligence Based Control etc.

Piyush Saxena received her B.Tech degree in 1981 from B. C. E., Patna and M.Tech degree in 1986 from Delhi College of Engineering, Delhi University, respectively. She joined the industry in 1983 and served for two years. She joined Netaji Subhas Institute of Technology, Delhi in 1985. She is a Member of Institute of Electrical and Electronics Engineers (IEEE). She is an Associate Professor in Netaji Subhas Institute of Technology, Delhi and pursuing PhD in Renewable Energy from the same.

Vikas Kumar received his B.Tech in Instrumentation Engineering from Kurukshetra University and M.Tech Instrumentation and Control Engineering from Netaji Subhas Institute of Technology, Delhi University. Currently, he is working as a Teaching cum Reasearch Fellow in the Division of Instrumentation and Control Engineering, NSIT. His research area includes predictive control of drives and power converters, intelligent control techniques, sensorless control of servo drives and electric vehicle control.