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ANN based intelligent energy management control of hybrid vehicle for improving fuel consumption

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Abstract: *Every passing year hybrid electric vehicles are becoming popular. After so much improved result it seems to be one of the potential solutions of global problems like global warming, rise in fuel prices, pollution etc. Due to various non linear parameters which are included in developing hybrid electric vehicles many a time to develop and achieve this new emerging technology, its analytical procedure is time consuming and it requires simplifying assumption. One practical alternative to analytical and empirical method that is easy and more accurate is Artificial Neural Network (ANN). For modeling complex real world problem in many discipline, Artificial Neural Network have emerged as computational modeling tool. To reduce fuel consumption and emission problems environmental condition, driver's behavior and types of roadway were considered very influential. So to analyze the vehicle's performance all these factors are incorporate in the system and presented in this paper. Artificial environmental data for elaborating vehicles performance is created artificially by neural network. Model for road way, SOC, vehicle, driver behavior and environment condition were created and ANN is being developed for all models.*
Key words: *Artificial neural network (ANN), fuzzy logic, fuel consumption, hybrid vehicle.*

I. INTRODUCTION

As compared to normal gasoline vehicle, a hybrid vehicle gives less fuel consumption and carbon emissions. Control strategy is the main key objective which is to be held responsible for achieving the improved performance and success of hybrid vehicle. Control strategy oh hybrid vehicle is broadly divided in two types rule based strategy and optimal control strategy for both series and parallel vehicles. Various researchers are using rule based control which is based on human expertise, mathematical and heuristic information. Rules based are again categorized in three different types; rule based which uses human knowledge for writing rules. Fuzzy logic based, which have more robust structure and can provide flexibility to controller because of non linear structure and can easily deal with non linear problem of power splitting between two sources of controller. The last type of rule based control strategy isNeuro-fuzzy which is the combination of fuzzy logic and artificial neuro-fuzzy control.

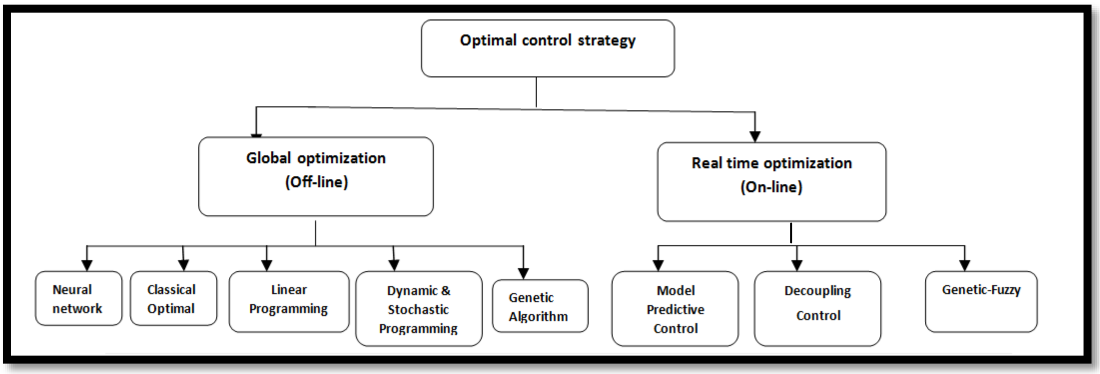

FIGURE 1: OPTIMAL CONTROL STRATEGY

Whereas the Optimal control strategy is another category which is further subdivides into global optimization (offline) and real time optimization (online) type. The optimal strategy is perfect and the controller is optimized according to cost function of system. But these controllers are sensitive to noise. Here both static and dynamic behaviors have to be taken into consideration for achieving optimized results.

Various researches have been carried out by combining various categories stated above for series as well as for parallel. ANFIS (adaptive neuro-fuzzy inference system) integrate the best features of fuzzy logic and neural network and so it has attracted the interest of researchers to synthesis controllers and to develop the models to explain past data and predict future behavior. ANFIS based online SOC (State of Charge) correction considering cell divergence for the EV (electric vehicle) traction batteries is developed [Haifeng Dai et al. (2014)].

Recent developments in artificial neural network (ANN) control technology have made it possible to train an ANN to represent a variety of complicated nonlinear systems [B. K. Bose (2007)]. ANN is a simulation of the human brain and nervous system built of artificial neurons and their interconnections. The ANN can be trained to solve the most complex nonlinear problems with variable parameters similar to the human brain. A neural network is an interconnected assembly of simple processing elements, units or nodes, whose functionality is loosely based on the neuron. The processing ability of the network is stored in the inter-unit connection strengths, or weights, obtained by a process of adaptation to, or learning from, a set of training patterns. The attractive feature of ANN is its

- Non linearity,
- High parallelism,
- Fault and noise tolerance
- Learning capabilities

II. VARIOUS ANN MODEL FOR HYBRID VEHICLES

Real time control strategy based of Elman neural network for the parallel hybrid electric vehicle is used by [Ruijun Liu et al. (2014)], their work discuss about equivalent fuel consumption function under charging and discharging conditions of batteries. The instantaneous control strategy and Elman neural network were simulated and analyzed in ADVISOR. Results prove 96% reduce simulation time and improve the real time performance of controller in addition with good performance of power and fuel economy.

In another work modeling, analysis, and simulation of an electric vehicle (EV) with two independent rear wheel drives were done. Generalized neural network algorithm proposed to estimate the vehicle speed. Neural network traction control approaches of an electrical differential system for an Electric vehicle (EV) propelled by two induction motor drives were stated. A practical speed estimation method for an induction motor was proposed where a recurrent neural network (RNN) with two hidden layers were used. RNN used called the Elman neural network. This algorithm were used to improve EV steering and stability during trajectory changes

Multi-Perceptron Neural Network were trained using Resilient Back Propagation algorithm to predict the suitable mode among between only motor modes, only engine mode, engine plus motor mode, charging mode and regenerative mode. The network trained to an error of 0.005 in 1300 iterations. After predictions of mode were done, the battery SOC (state of charge) was calculated. For energy optimization of hybrid algorithm shows 17.4% improvement in fuel consumption results. This hybrid algorithm can be used for both on line and online.

S.R. Bhatikar (1999) demonstrates the work energy storage system modeling based on neural network. The model maps the system's state-of-charge (SOC) and the vehicle's power requirement to the bus voltage and current. Work proposes and deploys new technique, smart select for designing neural network training data. When validated its predictive accuracy, measured by R-squared error was 0.97. The energy storage model using neural network simulated in Matlab environment. The results of simulation with the ANN incorporated in ADVISOR shows the matching with the original ADVISOR algorithm.

In one approach a neural network based trip model for highway portion was explained by [Qiuming Gong (2009)]. 3 inputs, 2 outputs network was developed for the fitting of the driving pattern on highway near on/off ramps. The trained neural network can obtain a good fitting of the driving pattern. The simplified approach makes the trip model on highway much easier. The interpolation model with NN is used and the fuel economy is greatly improved. The NN model presents a simplified and effective way for this detailed model of trip model considering the on/off ramp flows.

A new energy management system is proposed [Hamid Khayyam et al. (2014)] to improve the vehicle efficiency using a backwards-forwards simulation similar to the technique employed by ADVISOR [Khayyam H et al.(2011)],[Wipke KB et al. (1999)]. Models of vehicle engine, air conditioning, power train, and hybrid electric drive system were developed in addition with model for Road geometry and thermal conditions. Due to the nonlinear and complex nature of the interactions between parallel hybrid electric vehicles (PHEV),environment driver components, a soft computing based intelligent management system were developed using different fuzzy logic controllers. Applying a hybrid multi-layer adaptive neuro-fuzzy inference system and then optimized using genetic algorithm is capable of improving the fuel efficiency of the vehicle.

III. ARCHITECTURE OF ANN BASED APPROACH

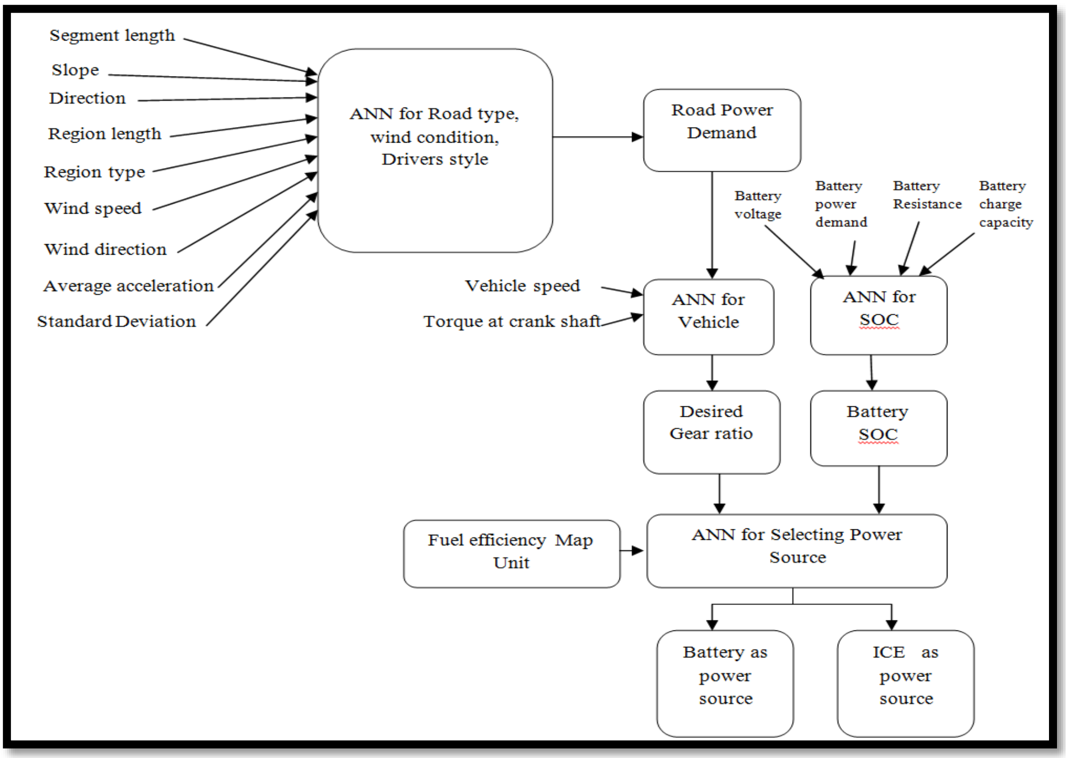

FIGURE 2: ARCHITECTURE OF ARTIFICIAL NEURAL NETWORK

To improve energy management strategy and to optimize the performance and efficiency of hybrid electric vehicle, modeling and simulation has become a very important approach for researchers. It also helps to reduce vehicle development time to larger extent and to optimize vehicle system design. Modeling and simulation helps in achieving insight into the functionality of the modeled vehicle systems and in investigating the systems behaviors and performance. To reduce fuel consumption and emission problem environmental condition, driver's behavior and types of roadway were considered very influential [11]. So to analyze the vehicle's performance all these factors should be incorporate in the system. To incorporate role of environment, roadway type and drivers style in simulation environment either real or artificial data is to be needed. But it is difficult many a time to use real or inadequate for extensive data for simulations. So artificial environmental data for, elaborating vehicles performance was created artificially by neural network using different models. The artificial data which was created poses the entire characteristic those of the real data for modeling and simulations. Model for road way, driver behavior and environment condition were created and ANN is developed for all models. To properly inspect the role of environment conditions in modeling and simulation two types of environment condition were used. One for road geometry and another for wind condition, that talks about weather condition. Real environment data many a time may not provide enough information therefore simulations are performed under control environmental condition. Comprehensive set of artificial data were created by different distribution in neural network [Khayyam et al (2013)]. Enormous slopes and bends exist in real world [13]. When roads are designed numerous geometric design methods could be used to smooth its physical slopes and bends. Carefully designed roads can help to optimize the performance of vehicle. A road has been constructed using a collection of segments. Xyz collected using sensor UDP i.e. application of android phone. Then based open the information collected from the sensor the segment length, bend, slope altitude direction all these parameters were decided. For this purpose equations stated by [Hamid Khayyam (2013)]were utilized and using these input and output data, ANN were trained. The roadway type LOS A, LOS B, LOS C,LOS D,LOS E and LOS F were generated at output with same concepts that were used by author to develop using ANFIS. Based on this training of ANN for road geometry was done. Similarly in order to model wind condition, region length, region type, and wind speed and wind direction were consider. Wind is highly metrological element both in speed and direction. And data regarding this were generated using various distributions. This data is again in term of 1, 45,000 units and this will helped to find out the drag force which the resistance coming from the wind. Then the model for driver's behavior was considered to generate driver's style at the output of ANN model. The concepts of ANFIS were used for generating calm, normal and aggressive style of driver. Average acceleration and standard deviation were generated by random variable ANN based modeling. Using all this information, vehicle speed, road power demand, torque at crank shaft (wheel) and crank shaft speed an artificial neural network for vehicle was designed which is going to give gear ratio and in term it is going to find out the power consumption and fuel consumption[Hamid Kayyam (2013),(2010)].

In order to know the state of charge of battery when it is cruising or moving, battery model fitted to Honda insight has been used. An ANN for battery has been generated by considering battery voltage, battery power demand, battery internal resistance and charge capacity of battery. Equations have been used to compute state of charge of battery. This state of charge decide the propulsion of vehicle and control strategy is only to make SOC as high as possible so that maximum propulsion would takes place by battery to achieve maximum fuel efficiency and also to reduce emission ,which is the prime objective of this work.

Depending on this gear ratio and state of charge of battery, an ANN has been developed for selecting power for hybrid vehicle. The decision was based on selecting battery or internal combustion engine. Fuel efficiency map unit was also used to compare the result..

1.1 ANN FOR ROAD WAY TYPE

An ANN for road geometry has been developed by considering segment length, Bend, slope of the road and altitude direction of specific road. A road has been constructed using a collection of segments. Xyz collected using sensor UDP i.e. application of android phone. Total 1, 45,000 positions were recorded. Then based open the information collected from the sensor the segment length, bend, slope altitude direction all these things were decided and ANN was trained. The roadway type LOS A, LOS B, LOS C, LOS D, LOS E and LOS F were generated at output with same concepts that have already been used for ANFIS by author.

Using the available Cartesian coordinates, the altitude (ALT), direction (DIR), and slope angle (Slope) of the road can be calculated as follows:

$$ALT = z \qquad (1)$$

$$DIR = \frac{180X \ arc \ tanget \ \frac{dx}{dy}}{\pi} \qquad (2)$$

$$D = \sqrt{x^2 + y^2 + z^2} \qquad (3)$$

$$\text{Slope} = \frac{dz}{dy} \qquad (4)$$

The random numbers for height and bend could be small or large for varying degree of height and bends into different road segment. The data bases were generated by using above equations for altitude (1), direction (2), distance (3) and slope (4). Using this data base roadway type was decided.

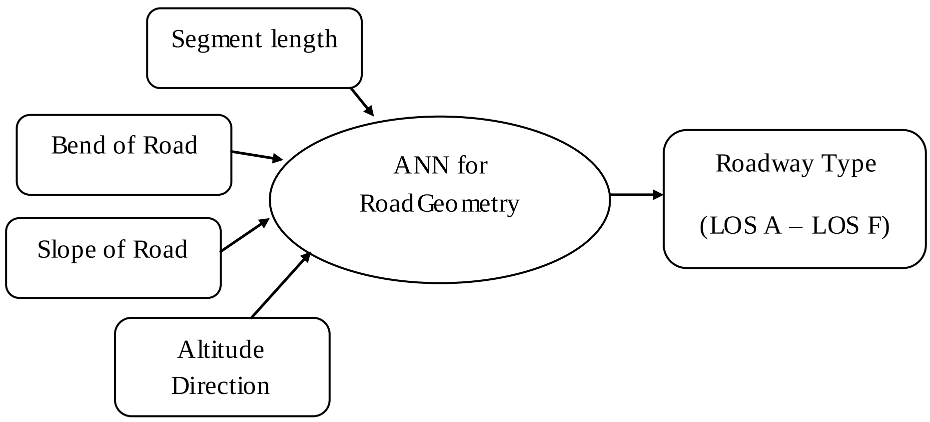

FIGURE 3: ANN MODEL FOR ROAD GEOMETRY

1.2 ANN FOR WIND

The empirical distributions of real wind direction data could not be well fitted by any form of standard distributions. One very simple approach was applied by considering uniform distribution upon an interval with the minimum and maximum values respectively. Speed and direction are the two parameters which have been consider for future simulation. A wind is constructed using a collection of regions of differing lengths. A wind creation algorithm is an iterative routine. The algorithm creates wind speed and direction values for each region. Random numbers were used to generate region length, wind speed value in the region, and also for wind direction in the region.

In order to model wind condition –we have consider region length ,region type , wind speed and wind direction and data regarding this were generated using various distribution from proper references . This data is again in term of 1, 45,000 units and this is utilized to find out the drag force which is the resistance coming from the wind. The equation which was used to calculate this drag force is shown below.

$$force = C_{drag\,(\Phi)} \frac{1}{2} \rho (V_\omega + V_t)^2 A_\Phi V_t - m_g \sin\theta\, v_t \qquad (5)$$

Wherec_{draq} is draq coefficient, ρ- air density, A-front area, Vω —wind velocity, Φ-wind angle

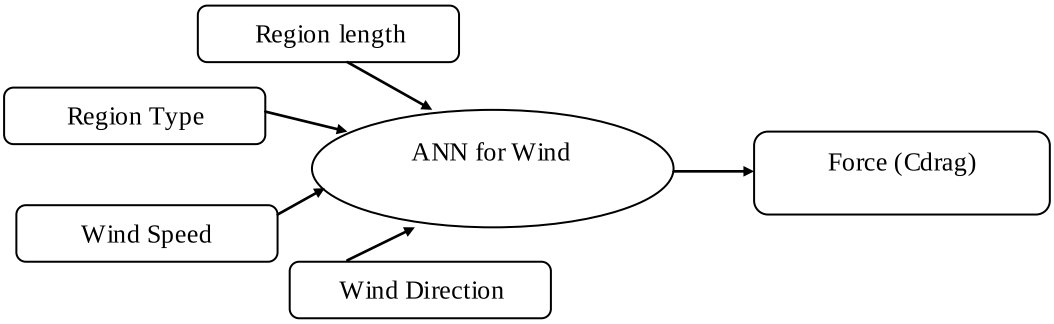

FIGURE 4: ANN MODEL FOR WIND

1.3 ANN FOR DRIVER BEHAVIOR

[De- Velieger et al. (2000)] stated three different style or behavior of driver by comparing on how they are using acceleration — Calm driving, normal driving and aggressive driving.

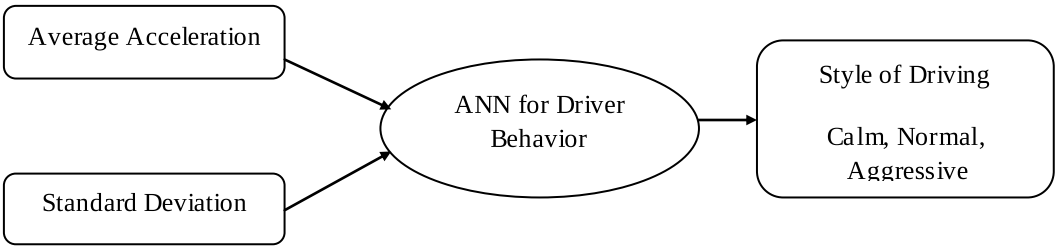

FIGURE 5: ANN FOR DRIVER BEHAVIOR.

Driver with calm driving follows all the traffic rules and avoid all the hurdles of road very calmly by avoiding hard acceleration and instant braking during driving. For normal driving driver uses moderate acceleration and normal braking. And for aggressive driving driver uses sudden acceleration hard braking and sudden gear change. Emissions and fuel consumption obtained from aggressive driving is always high compared to normal and calm driving. Average acceleration and Standard Deviation (SD) of acceleration over a specific driving range were used to identify the driving style. Acceleration criteria for the classification of the driver's style are based on the acceleration ranges proposed here. Average acceleration is considered from 0 to 0.9207 and standard deviation of acceleration is 0 to 0.8. Model for ANN were developed by using average acceleration and standard deviation. Data base for both were generated by using random function in neural network environment. Neural network was trained by using the data base generated. Depending upon the ranges specified network observes at output style of driver, i.e. calm, normal and aggressive. All three ANN of Roadway type, ANN of wind and ANN for driver behavior were club together and road power demand were created and it is used for developing ANN for vehicle[15][12].

1.4 ANN FOR VEHICLE:

In parallel hybrid electric vehicle, internal combustion engine and battery gives power to vehicle. A model for vehicle was developed using ANN to achieve proper gear ratio. Vehicle speed , road power demand , torque at crank shaft(wheel) and crank shaft speed were used by an artificial neural network for vehicle and was designed which is going to provide proper gear ratio and in term it is going to find out the power consumption and fuel consumption. For this particular thing we are using the flowing equation referred from references.

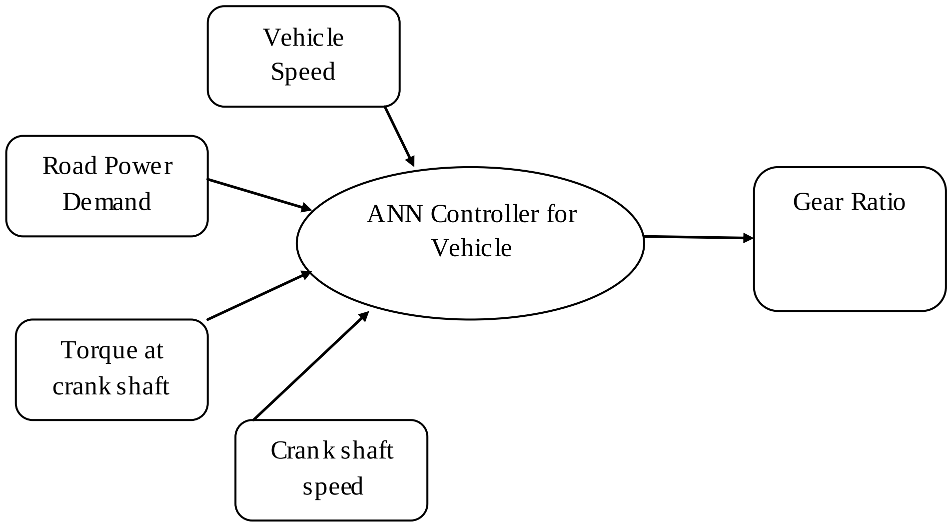

FIGURE 6: ANN FOR VEHICLE

$$P_{RPD(crolling\ )} = m_g \cos\theta V_t + C_{draq}\frac{1}{2}\rho(V_\omega + V_t)^2 A_\Phi V_t - m_g \sin\theta V_t \quad (6)$$

$$Z_d = \frac{\omega_{hr}}{d_r}\frac{1}{g_{r(t)}}\frac{P_{RPD}}{V_{(t)}} \quad (7)$$

$$\omega_{(t)} = \frac{d_r}{\omega_{hr}} g_{r(t)} V_{(t)} \quad (8)$$

$\omega_{(t)}$is crank shaft speed ,d_r is differential ratio , $g_{r(t)}$ is selected gear ratio and $V_{(t)}$is vehicle speed.

$$T_{Q(Wheels\ )} = T_{Q(engine\ )} XTransmissionratio\ for\ chosen\ gearXAxle\ ratio \quad (9)$$

$$Speed\ Vehicle = \frac{engine\ _{RPM} xTire\ _{Radius}\ x2\pi}{Transmission\ \ ratio\ \ x\ Axle\ ratio\ for\ chosen\ gear} \quad (10)$$

$$Power\ wheel = Power\ engine - Power\ losses \quad (11)$$

1.5 ANN FOR STATE OF CHARGE OF BATTERY:

Now in order to know the state of charge of that particular battery when it is cruising or it moving ,we have consider the battery model which is fitted to Honda insight and following are the parameters of the battery. In order to compute state of charge few equations stated below have been used for developing ANN for battery. In order to improve the overall efficiency it is necessary to indicate the actual charging level of the battery, the State of Charge (SOC) is often used [16]. However, the physical background of SOC has a strong relation with battery models based on current and voltage. The specification of battery used is as follows:

Table: 1 Specification of Battery

S. NO	PARAMETERS	SPECIFICATION
1	Lithium Ion	12v nominal voltage
2	Nominal capacity	26.2 AH
3	Number of cells in series	07
4	Number of modules in parallel	2
5	Back energy capacity	9.7kwH
6	Minimum voltage	9.5
7	Maximum voltage	16.5v
8	Internal resistance	0.05Ω

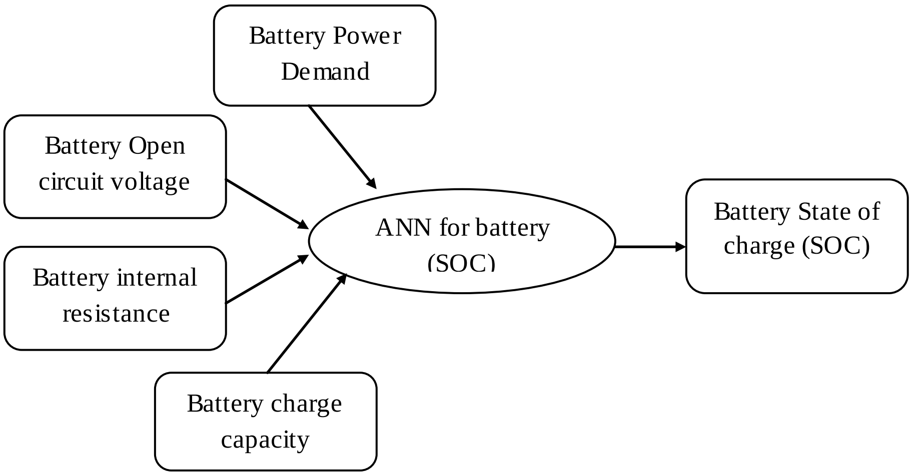

Figure 7: ANN model for battery SOC

Battery internal resistance(R) , open circuit voltage(voc), battery power demand (Pbat)and battery charge capacity(Q) are input parameters which allow for output voltage to be calculated based on battery state of charge (SOC).

Battery power availability information for charging and discharging is transmitted to the vehicle controller as well as to the electric drive components for propulsion and to accessories for miscellaneous use. An ANN has been developed for battery state of charge (SOC). Four inputs of battery internal resistance, open circuit voltage, and battery power demand and battery capacity were considered as input for developing this ANN. The following is the equation used to generate SOC as output of ANN.

$$SOC = \frac{VOC(soc) - \sqrt{VOC(soc)2 - 4PbatteryR}}{2QR} \quad (12)$$

Here in ANN VOC is taken between range 9.5 to 16.5V and it is generated by random distribution method. Battery power demand is from 0 to 9.7kwh which also generated by random distribution method. Battery internal resistance and battery charge are kept constant with a value of 0.05Ω and 26.2Ah. Using the data base generated proper value of SOC can be calculated to decide the power for propulsion by ANN. Using this state of charge value and proper gear ratio the algorithm for selecting power source is applied, which actually decide the power selection between internal combustion engine and battery. Fuel efficiency map unit plays a very major role of comparing the result obtained to make decision between two power sources. In PHEV one of the primary goals is to set the engine operation in its peak efficiency region. This improves the overall efficiency of the power train. The ICE operation is set according to the road load and the battery state of charge (SOC).

IV. SIMULATION RESULT

For this study advisor as reference software were considered. This is the customized software for parallel vehicle and Honda insight vehicle is available for in this particular software. Considering it is a reference for one particular cycle of 1.7 km following results were obtained. Fuel consumption of ANN and ANFIS matches with the fuel consumption of Advisor.

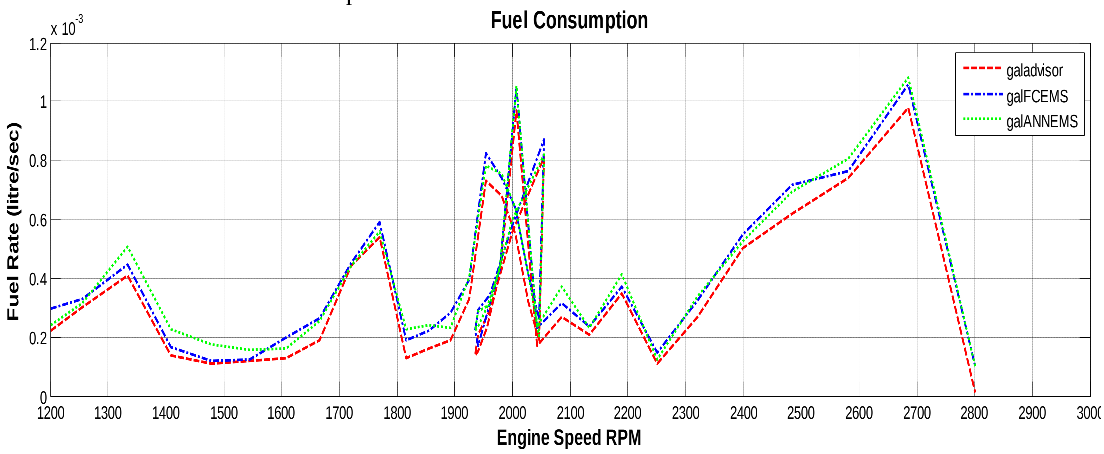

Figure 8: Fuel consumption curve

Then power consumption shows similar trend only difference is that it has certain picks which is moving away from advisor the reason might be probalistic nature of fuzzy logic or anfis or neural network

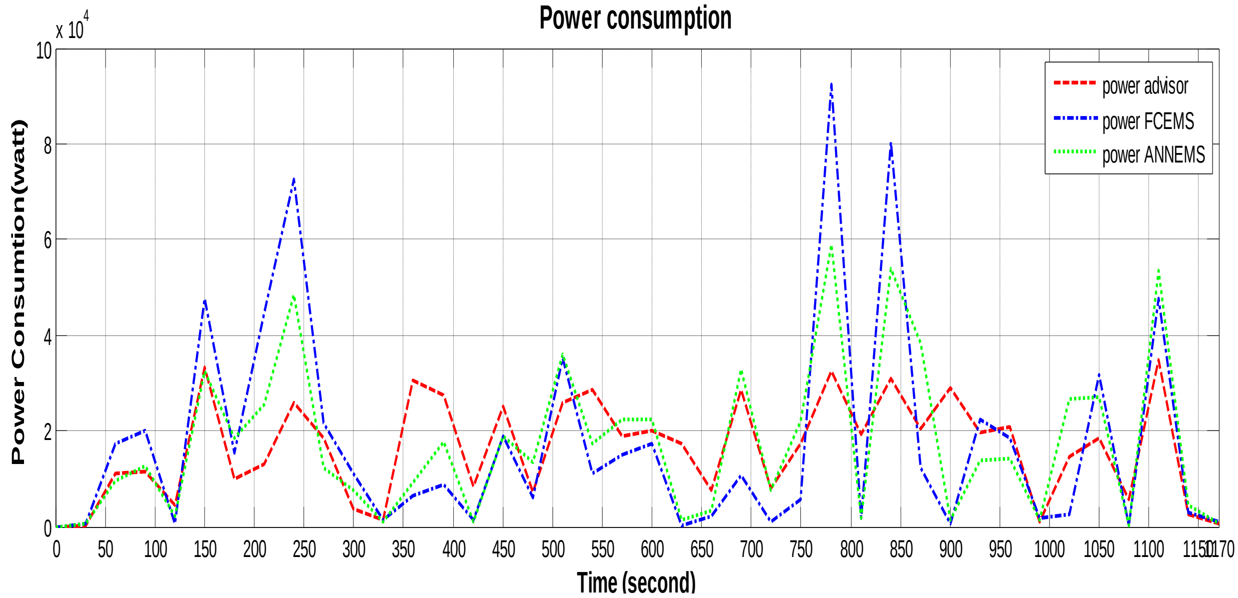

Figure 9: Power consumption curve

Then these results are about the torque demand and this demand is coming from driver to drive the vehicle. Fig (9) shows that all 3 plots are properly match.

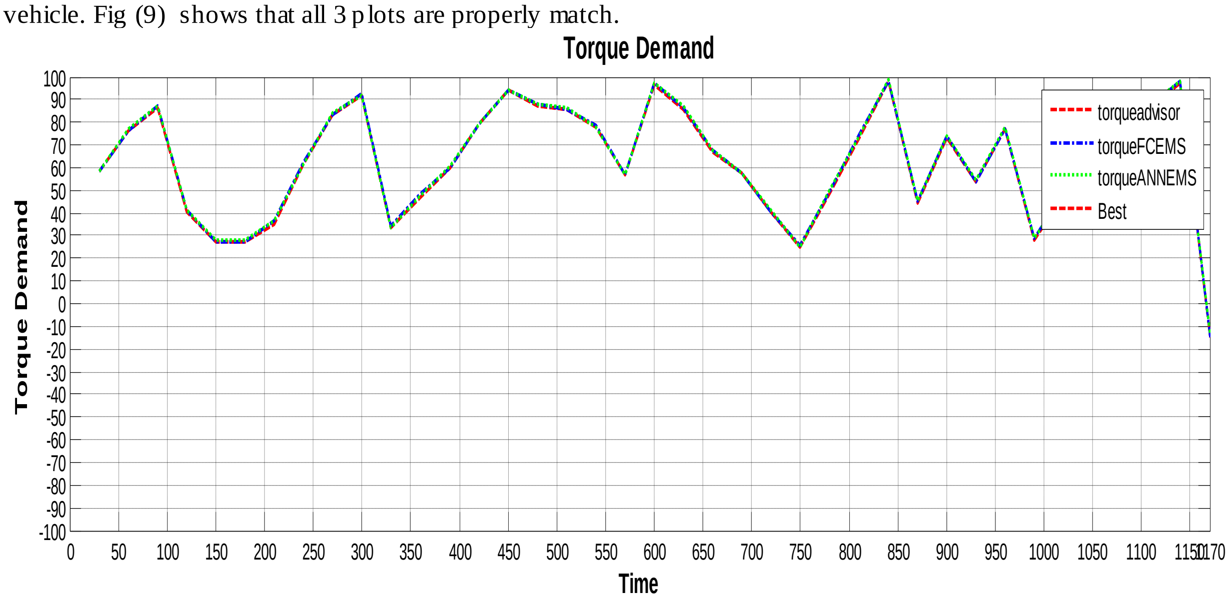

Figure 9: Torque Curve

The compiled results are shown in Table 2. Trip length considered was 1.7km and duration of travel is consider 1170 sec and have observed that fuel consumption is around 15% more in case of ANFIS and ANN as compared to advisor where 4.1 E -04 is average value and 15 is percentage value. The power consumption is more by 7.2 and 8% in ANFIS and ANN as compared to advisor. The torque demand is slightly more in ANFIS and ANN. And battery soc needs to rectify this in current it is 10 and 20% more.

Table 2Comparison of ANFIS and ANN based controller performance with ADVISOR

Parameter	Trip length	Duration	Fuel Consumption(liter/sec)	Power Consumption(watt)	Torque(N-m)	Battery SOC(v)
ADVISOR	1.7km	1170sec	3.6E -04	16366	63.05	6.73
ANFIS	1.7km	1170sec	4.1E -04 (15%)	17306(7.26%)	63.61(0.9%)	7.41(10.15%)
ANN	1.7km	1170sec	4.2E-04(15.36%)	17715(8.79%)	63.72(1.07%)	8.1(20.32%)

V. Conclusion

ADVISOR software consists of all the specifications of Honda Insight. The default option of parallel hybrid vehicle was selected. The performance of ANFIS based controller & ANN based controller were validated with ADVISOR. The error in prediction of performance for ANFIS as well as ANN is between 0-10 percent as compared with ADVISOR. More trip length and variety of trips needs to be considering for proper validation of proposed methods. The environmental condition does affect the performance of controller and hence some more conditions need to be considered. Simulations results shows fuel efficiency and emissions along with power switching pattern is reduced to larger extent.

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