

# Modelling of an ANFIS Technique for Performance Improvement of Hybrid Electric Vehicle

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**Abstract**— With growing oil prices and escalating environment worries, cleaner and supportable energy solutions are demanded. Present transportation contributes large amount of energy consumption and emission of pollutants. In this work, hybrid vehicle technology has been analyzed, with Power split configuration having internal combustion engine and battery as the power source. Initially the analysis of Series parallel hybrid electric vehicle (SPHEV) performance is done with battery of higher amp-hr. capacity. In advanced state the converter circuit is implemented to reduce the battery rating. Different cases have been observed with different charging and discharging circuitry of battery. To improve modeling accuracy, MATLAB (Simscape/Simdriveline/Simulink) tool is used for simulation, discovering the possibilities of advanced hybrid power train architectures and energy storage system designs. To improve the controlling behavior of Hybrid electric vehicles robust controller (i.e. ANFIS) are admired because of their ability to achieve related performance to a standard automobile while prominently improving fuel efficiency and tailpipe emissions. SPHEV is combination of the series and parallel Hybrid electric vehicle configuration. Though having complex architecture SPHEV are preferred over simple power trains because of its advances and advantages. The work can be analyzed with different sources like Fuel cell, as the energy source to the vehicle, making the less use of fossil fuel.

**Keywords:** Electric Vehicle, ANFIS, Spehvs, Energy Optimization, Energy Storage

## I. INTRODUCTION

Hybrid vehicles rely on two or more energy converters for generating propulsion. Each energy converter is fed by an appropriate on-board energy reservoir. A hybrid electric vehicle (HEV) is comprised of an internal combustion engine together with one or more electric machines [1]. The engine converts fossil fuel from the fuel tank into mechanical power while the electric machine(s) convert(s) electric energy from an electric energy storage system, such as a battery, into mechanical power. Unlike the combustion engine, an electric machine is usually able to reverse the process by operating as a generator thereby converting mechanical power into electric energy [2]. Augmenting the conventional drive train with an electric path is primarily motivated by the potential of better fuel economy. This potential is realized by: 1) engine stop-start; 2) operating point shifting; 3) engine downsizing without loss of drivability such as acceleration performance; 4) recuperation of kinetic energy during deceleration; and 5) pure electric zero-emission driving. The drawbacks of electric hybridization are increased weight, complexity, and cost.

A number of hybrid electric drive train topologies exist, such as the series, the parallel, and the combined (or

series-parallel) topology. Within each topology, a number of variants exist [3]. This HEV power train is of the series-parallel type, such as the one found in the Toyota Prius car. This HEV has two kinds of motive power sources: an electric motor and an internal combustion engine (ICE), in order to increase the drive train efficiency and reduce air pollution. It combines the advantages of the electric motor drive (no pollution and high available power at low speed) and the advantages of an internal combustion engine (high dynamic performance and low pollution at high speeds) [4].

## II. RELATED WORKS

Karen et al (1999) presented a simulation and modeling package developed at Texas A&M University, V-Elph 2.01. V-Elph was written in the Matlab/Simulink graphical simulation language and is portable to most computer platforms [5]. They also discussed the methodology for designing vehicle drivetrains using the V-Elph package. An EV, a series HEV, a parallel HEV and a conventional internal combustion engine driven drivetrain have been designed using the simulation package. Simulation results such as fuel consumption, vehicle emissions, and complexity are compared and discussed for each vehicle.

Ma Xianmin (2002) developed a novel propulsion system design scheme for EVs requiring high power density. The theory analysis of mathematical models of EV are first set up based on the vehicle dynamic characteristics, then the whole system is divided into seven function blocks according to power flow, the simulation models are formed in the MATLAB language. The simulation results are verified in a PDM AC-AC converter, which shows that the suggested method is suitable for EV [6].

Brian (2007) created a model in MATLAB and ADAMS to demonstrate its fuel economy over the conventional vehicle. He used the Honda IMA (Integrated Motor Assistant) architecture, where the electric motor acts as a supplement to the engine torque. He showed that the motor unit acts as generator during the regenerative braking. He used a simple power management algorithm in the power management controller he designed for the vehicle [7].

Cuddy and Keith (2007) performed a parallel and series configured hybrid vehicles likely feasible in next decade are defined and evaluated using a flexible Advanced Vehicle Simulator (ADVISOR). Fuel economies of two diesel powered hybrid vehicles are compared to a comparable technology diesel powered internal combustion engine vehicle. The fuel economy of the parallel hybrid defined is 24% better than the internal combustion engine vehicle and 4% better than the series hybrid [8].

Bauml and Simic (2008) discussed the importance of vehicle simulations in designing the hybrid electric vehicles. A series hybrid electric vehicle simulation with the simulation language Modelica was developed. They

explained the simulation approach [9]. They concluded with some of the simulation results emphasizing the simulation importance. Zhou and Chang (2008) established powertrain dynamic simulation model of an integrated starter/generator (ISG) hybrid electric vehicle (HEV) using Simulink. The parallel electric assist control strategy (PEACS) was researched and designed. The analysis of dynamics performance and fuel economy of the model was carried out under the FTP drive cycle, which can provide a design reference for the setup of the powertrain test bench. The results show that the fuel consumption can be effectively reduced by using the designed PEACS with the state-of-charge of the battery maintaining in a certain scope [10].

Kuen-Bao (2008) described the mathematical modelling, analysis and simulation of a novel hybrid powertrain used in a scooter [11]. The primary feature of the proposed hybrid powertrain is the use of a split power-system that consists of a one-degree-of-freedom (dof) planetary gear-train (PGT) and a two-dof PGT to combine the power of two sources, a gasoline engine and an electric motor. Detailed component level models for the hybrid electric scooter are

established using the Matlab/Simulink environment. The performance of the proposed hybrid powertrain is studied using the developed model under four driving cycles. The simulation results verify the operational capabilities of the proposed hybrid system [12].

### III. RESEARCH METHODOLOGY

#### A. Proposed Model

Fig. 1 presents the block diagram of a HEV power train with an electrical machine and an ICE that are combined together to drive the vehicle [13]. The electrical machine works as generator when the state of charge (SOC) of batteries is 0low and there is need to charge the batteries, and works as motor when a torque is needed for driving the vehicle. The controller, designed by neuro-fuzzy method, controls the engine by changing the throttle angle in order to produce the required torque [14]. The torque requested from electric motor is calculated by subtracting the real engine output torque, from the desired torque at any time

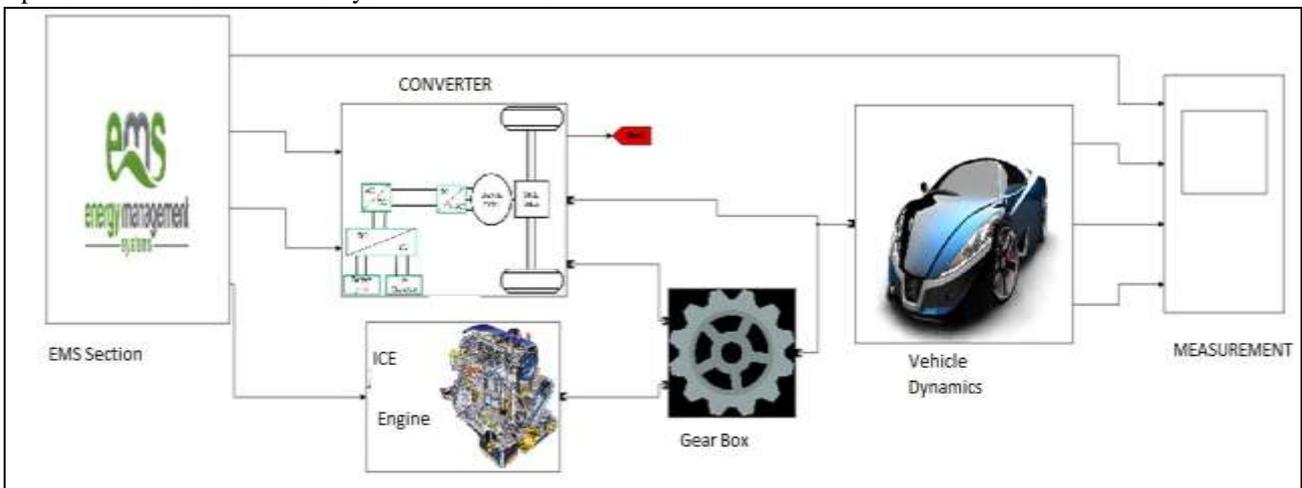


Fig. 1: Model of series Parallel HEV

We use an electric motor and its controller model, which has been defined in ADVISOR 2002 software [15]. In this software, the losses in the electric motor and its controller as well as the rotor inertia, and the dependency of speed to

the toque have been considered fig 2. Motor controller ensures that the maximum motor current is not exceeded and that the electric motor is not working when it is not needed [16].

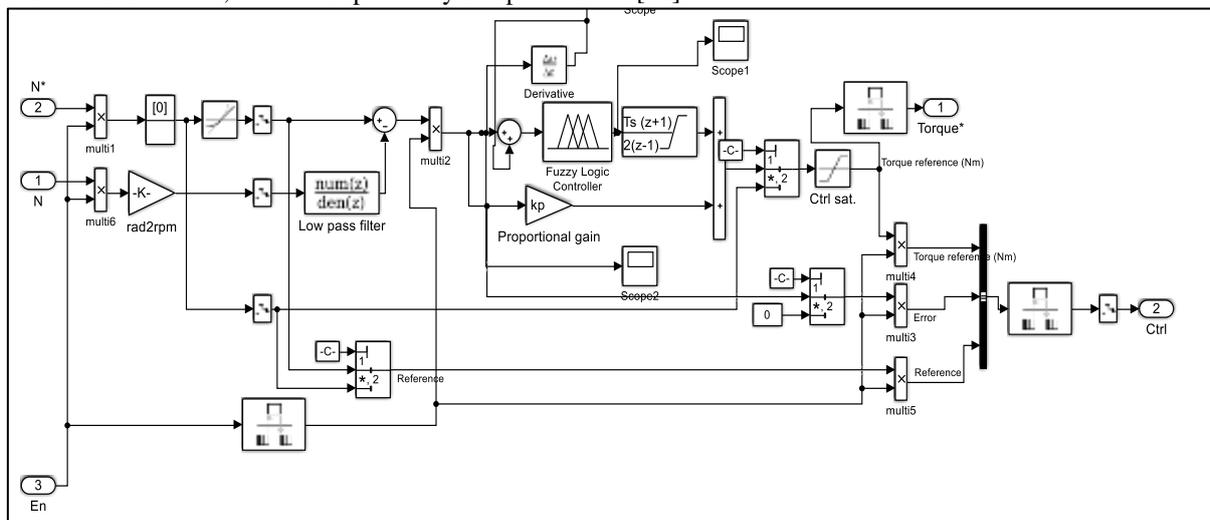


Fig. 2: speed control drive using ANFIS

The battery is a 6.5 Ah, 200 Vdc, 21 kW Nickel-Metal-Hydride battery. The DC/DC converter (boost type) is voltage-regulated fig 3. The DC/DC converter adapts the low

voltage of the battery (200 V) to the DC bus which feeds the AC motor at a voltage of 500 V [17].

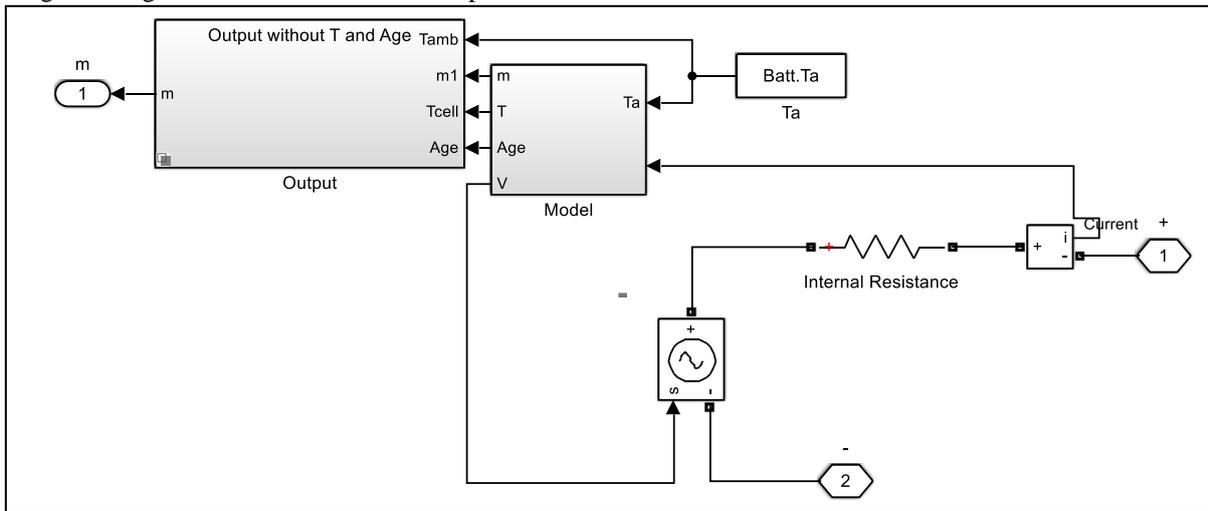


Fig. 3: Model of Battery used for storage

**B. ANFIS**

Adaptive control and neuron fuzzy control are two advanced methods for time-varying and non-linear processes [18]. This course will begin with adaptive control of linear systems. Nonlinear systems and related control issues will be then

briefly reviewed fig 4[19]. Neural network and fuzzy model will be described as general structures for approximating non-linear functions and dynamic processes [20]. Based on the comparison of the two methods, neuron fuzzy model will be proposed as a promising technology for the control and adaptive control of nonlinear processes.

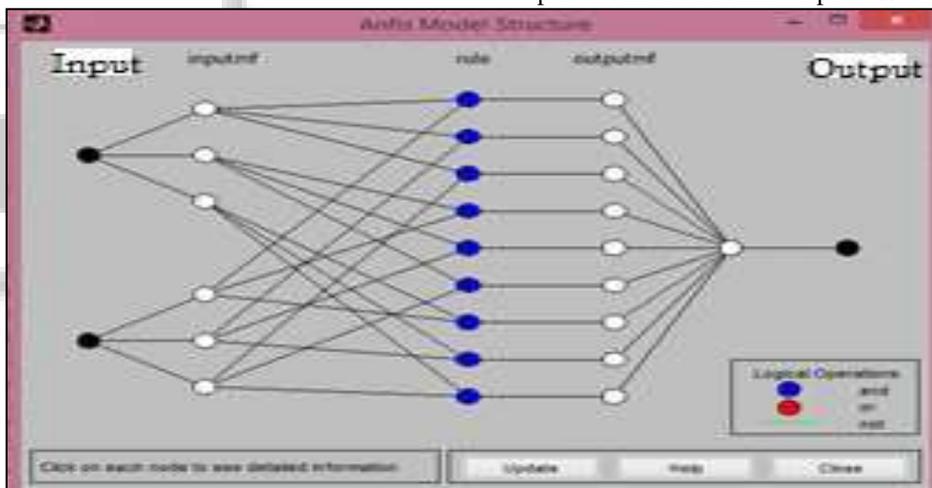


Fig. 4: ANFIS rule structure for hev

**C. ANFIS STRUCTURE**

The adaptive network-based fuzzy inference systems (ANFIS) is used to solve problems related to parameter identification [21]. This parameter identification is done through a hybrid learning rule combining the back-propagation gradient descent and a least-squares method.

simulations have been done MATLAB R 2014b with a 4GB RAM computer with core i3 processor[22].

**B. Simulation and Results in MATLAB**

The current graph in case of our proposed algorithm ANFIS is shown below. It should run for about one minute when you use the accelerator mode. You can see that the HEV speed starts from 0 km/h and reaches 73 km/h at 14 s, and finally decreases to 61 km/h at 16 s. This result is obtained by maintaining the accelerator pedal constant until the end of the simulation using ANFIS controller. Open the scope “Car” in the main system. The following explains what happens when the HEV is moving and the stator current after the implementation of ANFIS is shown in fig 5.

**IV. SIMULATION RESULTS AND DISCUSSION**

**A. Results**

This section discusses the various simulation results obtained by implementing the proposed algorithm explained in previous section for our problem statement. All the

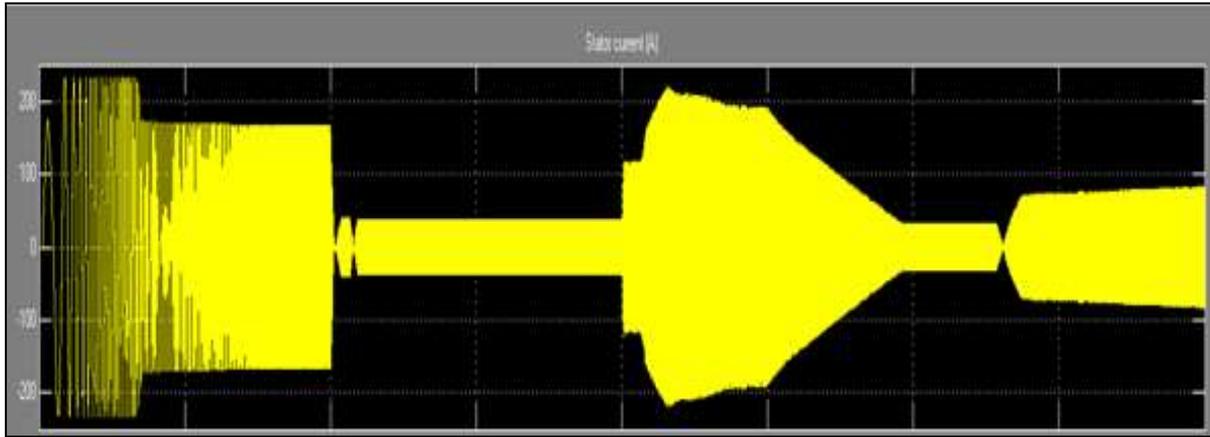


Fig. 5: Plot of stator current incorporated with ANFIS

At  $t = 0$  s, the HEV is stopped and the driver pushes the accelerator pedal to 70%. As long as the required power is lower than 12 kW, the HEV moves using only the electric motor power fed by the battery. The generator and the ICE provide no power.

Similarly rotor current can be plotted after applying ANFIS controller shown in figure 6. This controller is implemented in the motor section.

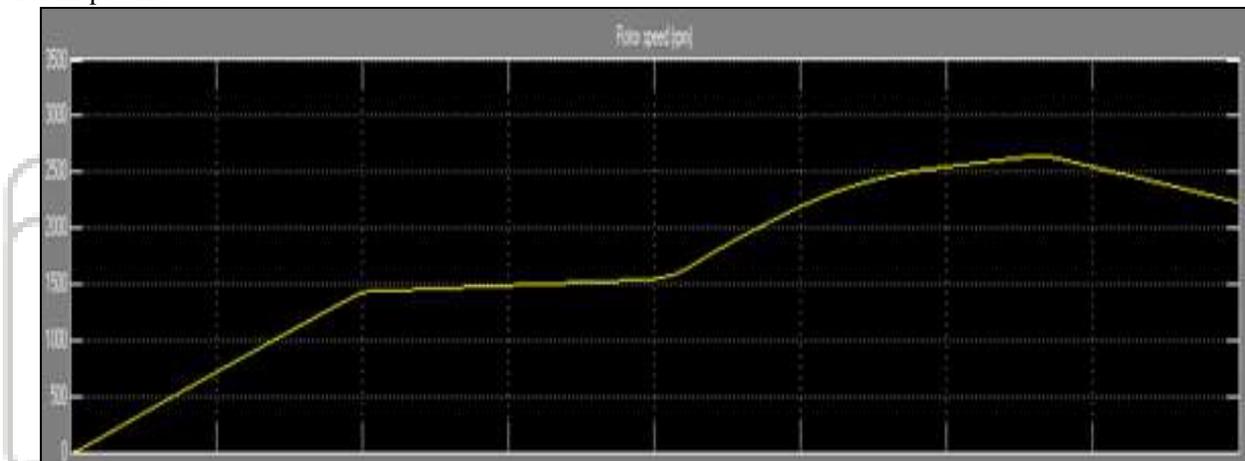


Figure 6: Plot of rotor current incorporated with ANFIS

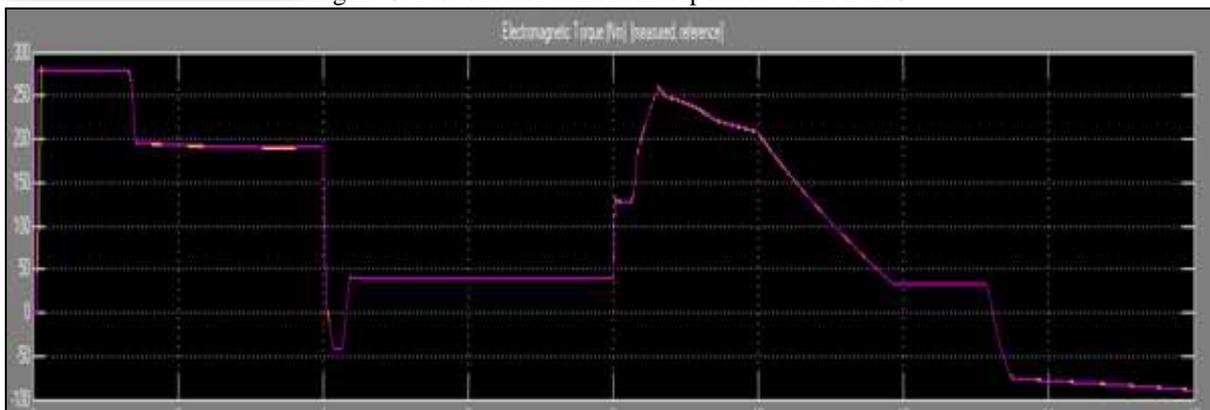


Fig. 7: Torque development with ANFIS controller

At  $t = 4$  s, the accelerator pedal is released to 10% (cruising mode). The ICE cannot decrease its power instantaneously; therefore the battery absorbs the generator power in order to reduce the required torque.

At  $t = 4.4$  s, the generator is completely stopped. The required electrical power is only provided by the battery.

At  $t = 8$  s, the accelerator pedal is pushed to 85%. The ICE is restarted to provide the extra required power. The total

electrical power (generator and battery) cannot reach the required power due to the generator-ICE assembly response time. Hence the measured drive torque is not equal to the reference.

At  $t = 8.7$  s, the measured torque reaches the reference. The generator provides the maximum power.

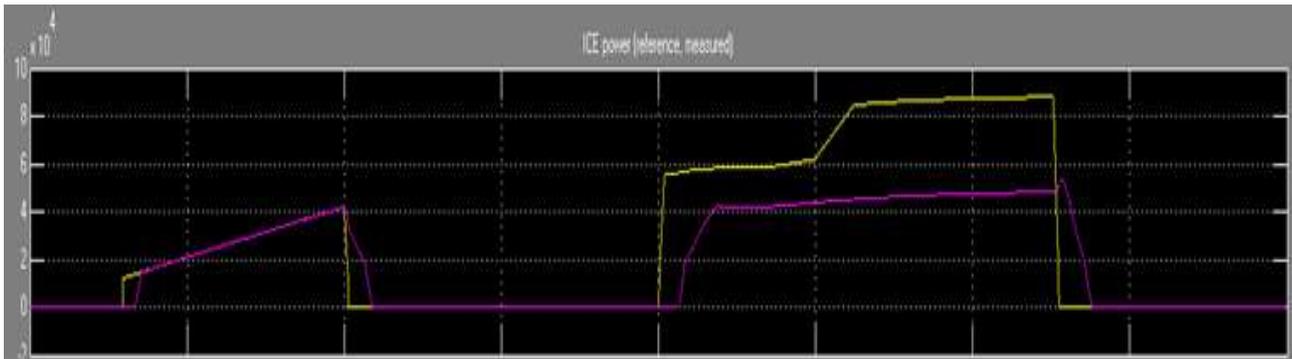


Fig. 8: ICE measured and reference power

At  $t = 10$  s, the battery SOC becomes lower than 40% (it was initialised to 41.53 % at the beginning of the simulation) therefore the battery needs to be recharged. The generator shares its power between the battery and the motor. You can observe that the battery power becomes negative. It means that the battery receives power from the generator and recharges while the HEV is accelerating. At this moment, the required torque cannot be met anymore because the electric motor reduces its power demand to recharge the battery.

At  $t = 13$  s, the accelerator pedal is set to -70% (regenerative braking is simulated). This is done by switching off the generator (the generator power takes 0.5 s to decrease to zero) and by ordering the motor to act as a generator driven

by the vehicle's wheels. The kinetic energy of the HEV is transformed as electrical energy which is stored in the battery. For this pedal position, the required torque of -250 Nm cannot be reached because the battery can only absorb 21 kW of energy.

At  $t = 13.5$  s, the generator power is completely stopped.

Some interesting observations can be made in each scope. During the whole simulation, you can observe the DC bus voltage of the electrical system well regulated at 500 V. In the planetary gear subsystem, you can observe that the Willis relation is equal to -2.6 and the power law of the planetary gear is equal to 0 during the whole simulation.

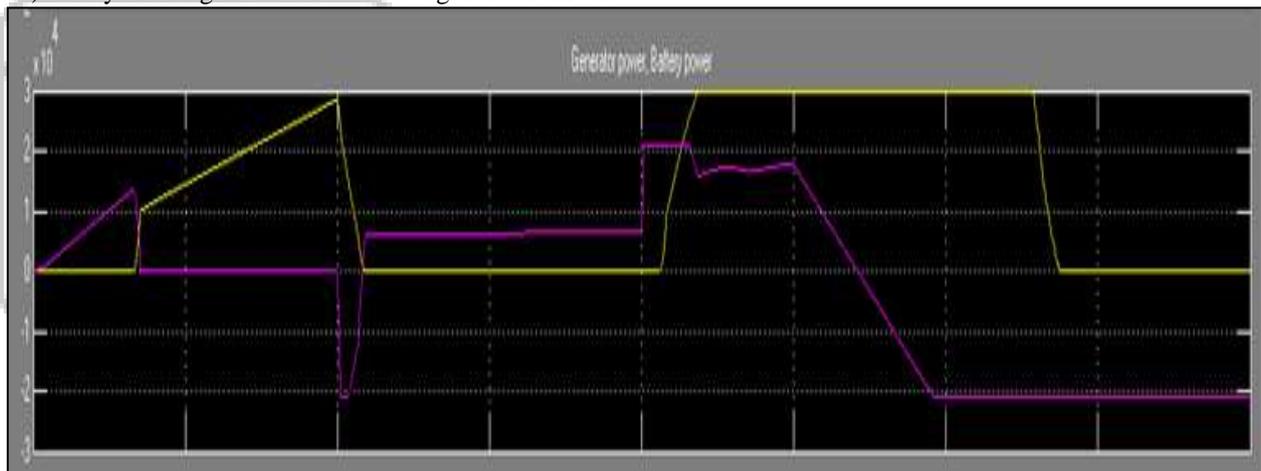


Fig. 9: Generator Power and Battery output power

The control on HEV is more effective if we observed from each point of time scale with magnitude of current and power as shown in figures above.

## V. CONCLUSION

As mentioned in the synopsis report a frame of hybrid electric vehicle (HEV) designed by means of robust controller i.e. ANFIS gives better response in comparison with different biological controller. In the modeling and feedback control of any dynamical system, a controller is a must for the plant as it takes care of all the disturbances and brings back the system to its original state in a couple of second. To start the design of the controller using the ANFIS scheme, first, a Simulink model of the motor plant along with the controller mathematical model is required, which can be further used for simulation purposes.

## VI. FUTURE SCOPE

The above problem has been discussed based on translating expert knowledge into a set of ANFIS rules. There is no mathematical model behind it, if more refined rules are used, a potential improvement in system performance can result. The mathematical model can also be refined by considering the uncertainty and parameter variations and using robust control algorithms for solving the optimization problem.

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