ENERGY CONTROL STRATEGIES AND RESPONSE OF A SERIES-PARALLEL HYBRID ELECTRIC VEHICLES ON FTP-75 DRIVE CYCLE.

[1]Abrar Ahmad, [2]Md. Sajjad Ahmad, [3]Maksood

[1]Assistant Professor, [2]Ph.D Scholar, [3]M.Tech
[1]*Department of Electrical Engineering,*
[1]*Jamia Millia Islamia*, New Delhi, India,

Abstract : The rapid development of Intelligent Transportation Systems (ITS) offers great opportunities to improve the overall performance of Energy Management Strategies (EMS) for connected hybrid electric vehicles (HEV). The objective of the proposed energy management system is to focus on increasing the battery life, reduction of ripple and improvement in system efficiency. In this paper energy management strategies of HEV as well as integrated energy storage systems has been explored in series-parallel hybrid mode. The objective of the proposed energy management system is to focus on exploiting the super capacitor characteristics along with improved battery lifetime and system efficiency. The role of the energy management system is to yield battery reference current, which is subsequently used by the controller of the DC/DC converter. The model is developed and simulated on MATLAB SIMULINK software.

***IndexTerms* - Hybrid electric vehicle, charging strategy, intelligent technique, Fuzzy Logic.**

I. INTRODUCTION

Hybrid electrical vehicle is a combination of internal combustion engines and electric motors. Hybrid vehicles exploit the best benefits of both types of vehicular technologies viz IEC Engines and motor based electric vehicles. Hybrid electric vehicles can broadly be categorized into three of its variants; i.e. series hybrids, parallel hybrids, and series-parallel hybrid as shown in Figure 1.1, 1.2 and 1.3 respectively. In the series-hybrid electric vehicles engines are not directly connected to drive wheels but rather engines are connected to the converter and the converter in turn is connected to the motor which drives the vehicle as depicted by the schematics in Figure 1.1.

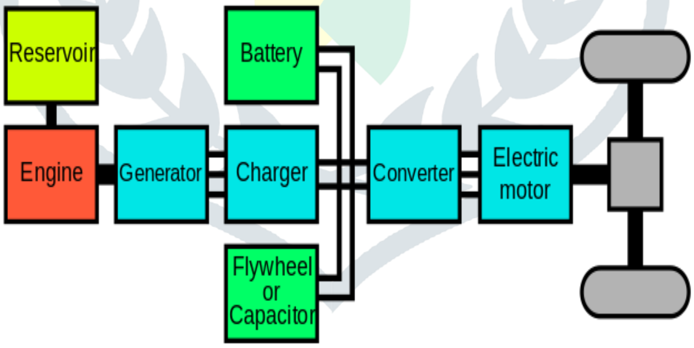

Fig. 1.1 Series hybrid

In parallel-hybrid electric vehicles, engines are directly connected to drive wheels while IC engines and electric motors are connected through the mechanical coupling. This arrangement gives this variant an edge in performance as compared to series-hybrid electric vehicles. The schematic is depicted in Figure 1.2

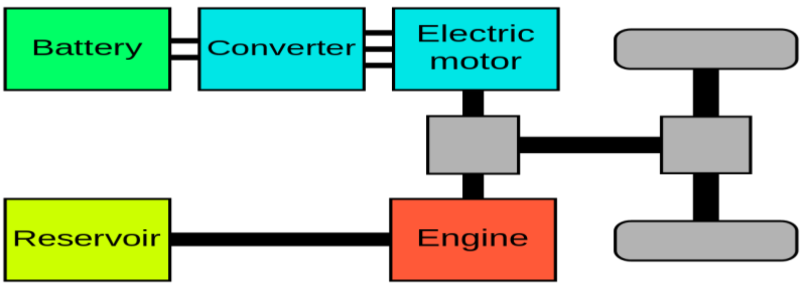

Fig.1.2 parallel hybrid electric vehicle

In series-parallel hybrid electric vehicles shown in Figure 1.3 engine can directly power the drive train as in parallel hybrid system but can also power converter which in turn helps drive motor. Series parallel hybrid system is capable of providing continuous high output power as compared to both series-hybrid as well as parallel-hybrid power trains.

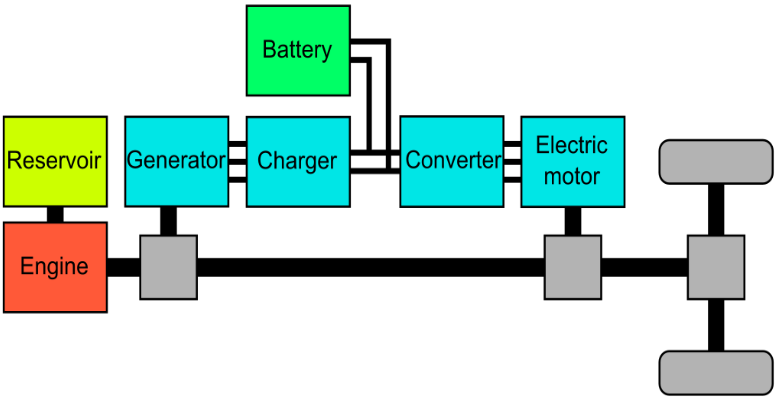

Fig.1.3 Series –parallel hybrid

II. ENERGY MANAGEMENT STRATEGIES (EMS)

There are different types of energy management as depicted in the Figure 2.1. The main motive for using different types energy management techniques is to satisfy the driver's power demand with minimum fuel consumption. Strategies such as linear programming, dynamic programming, genetic algorithm, and fuzzy control strategies [5] are widely used.

A. *Fuzzy Rule Based Control Strategies*

First L. A. Zadeh uses the word fuzzy logic, which defines the mathematics of fuzzy set theory. Its unique strategies to solve a mathematics problem. And it is used for representing system or linguistic labels, slow, medium, fast, high, and low. Truth is the matter of degree in fuzzy logic, and it's easy to control or easy to realize. Fuzzy logic has strong robustness. There are some other techniques under fuzzy control strategies is that adaptive control strategies and predictive control strategies. Adaptive optimize both emission and system efficiency. Through these techniques, we can find an optimal operating point. [5] Have different driving techniques /conditions

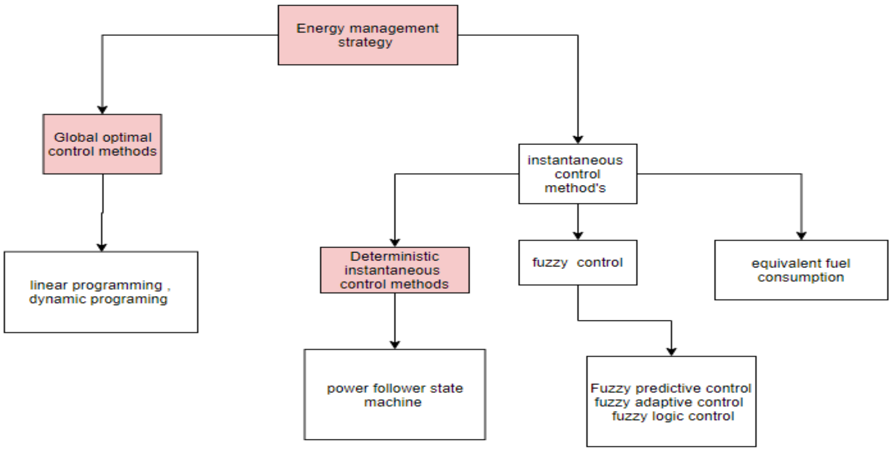

Fig.2.1 Energy Management Strategies

B. *Optimization Based Control Strategies*

Our motive for using these techniques is to minimize the cost function. This function includes fuel consumption, emission, and torque depending on the application. This technique is not directly used for real-time energy management. These strategies can be divided into 2 types, Global optimization, and real-time optimization.[7] Global optimization techniques contain the knowledge of the whole drive pattern which includes driving response, battery SOC, and route. There are some other techniques also used to solve this type of issue for example linear programming, dynamic programming, and genetic algorithm. [14] In these techniques, we assume minimizing fuel consumption, reduce pollution.

C. *Linear Programming*

This technique is more suitable for the series hybrid electric vehicle. For the assessment of fuel efficiency this programming strategy can be used. Non-linear problem can also be formulated which is almost or approximate as a linear programming problem. in this programming controlling the gear ratio and torque, an optimized design, and control of series hybrid vehicles are proposed. This technique provides an independent solution from any specific control law.

D. *Dynamic Programming*

This programming was used by Richard Bellman in 1940. Which is describes the problem-solving process. Which gives the optimum solution at the right time, its use for both mathematical and computer programming methods [10]. In both methods, working process for solving a problem is almost the same. Through this, we can solve both types of problems either linear or non-linear as well as constrained and unconstrained problems. We can use this method with other techniques, for example, an adaptive neural energy management system.

E. *Genetic Algorithm*

It's the most important algorithm to achieve an optimized solutions. The genetic algorithm is mostly used to minimize the transportation costs where the traffic density is higher specially in metropolitan cities where speed is below 20 km/h such as Bangalore, Mumbai, and Delhi. In these techniques, there is no need for any strong assumption or other objective parameters. But this method takes more time and doesn't provide a view to the designer.

F. *Other power management strategies and important definitions.*

There are some other power management strategies for example rule-based energy management with PI as a controller by using a super-capacitor. In these techniques, our focus is on battery life as well as battery efficiency[17]. First, we developed a simple rule but it should be effective for the development of a hybrid system. In this method, we use a proportional-integral (PI) controller which adjusts the load distribution between battery and capacitor. These techniques use batteries that have high energy density and relatively low power density. There is some non-linear function, for example, charging and discharging internal resistance. Comparison between various strategies is Shawn in the table-1

Table -1

Method	Structural Complexity	Computational Time	Type of Solution
Fuzzy Logic	N	S	G
Generic Algorithm	Y	M	G
Dynamic Programming	Y	M	G
Model Predictive	N	S	G
Neural Network	Y	S	G

Where G=Global, L= Local, Y=Yes, N=No, M=More, S=Small

III. Hybrid Topological Structures

Hybrid topological structure categories are adopted according to power flow between the battery and super-capacitors. We have four types of commonly used hybrid structures.

A. Passive Topological structure

In this structure battery and capacitors are connected in parallel as shown in the figure 3.1 We make configuration in this way both battery and capacitors have the same voltage but their current is fixed or manage by their internal resistance [1].

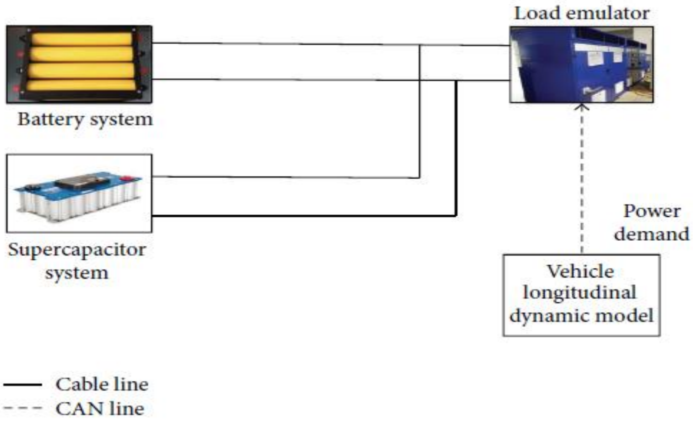

Fig.3.1 Passive topology structure

B. Semi active topological structure

In this structure DC-DC converter is connected on battery side. This can be connected with the converter along with super-capacitors or with Super capacitor as shown in Figure 3.2 (a) and (b). This topology can boost up the battery voltage, as well as reduce weight and volume of the overall topological structure.

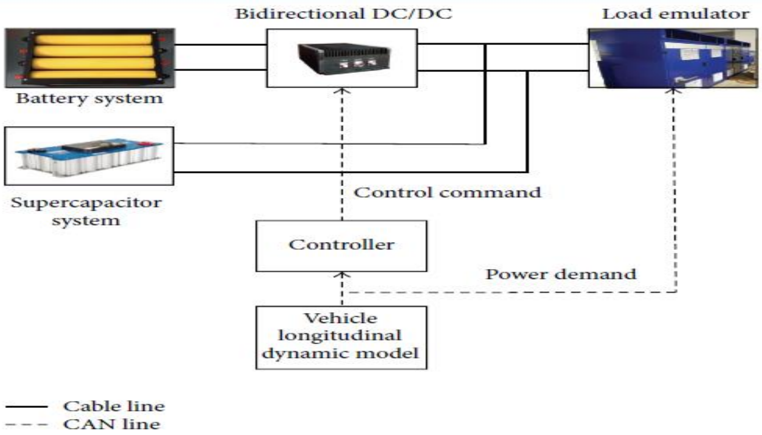

Fig. 3.2 semi-active topological structure (a)

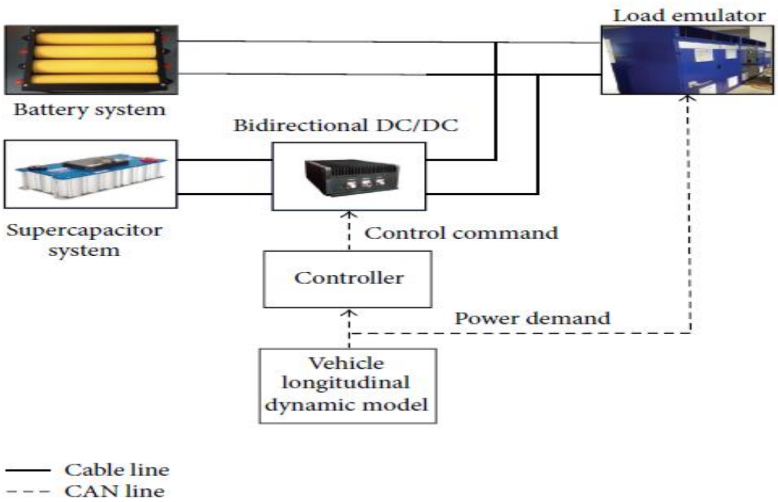

Fig. 3.2 semi-active topological structure (b)

C. Fully active topological structure

In this configuration 2 bi-directional converters are used. Through this, we can control power sources from any converter independently [2]. This structure is simpler, more flexible, more stable, and more efficient; but costlier. in this structure, we can control voltage as well as power distribution between the super-capacitor and battery

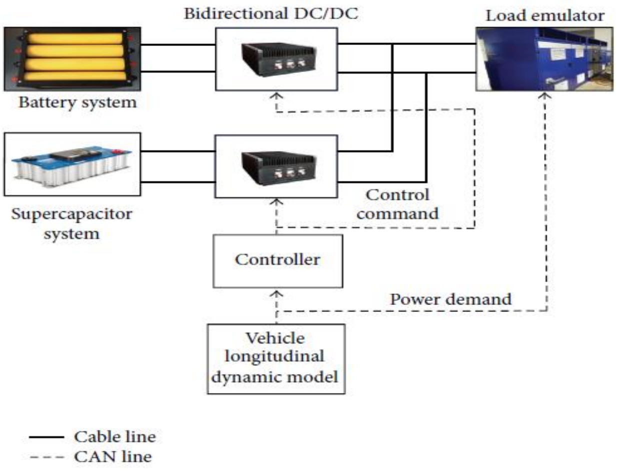

Fig.3.3 Fully active topological structure

IV. Hybrid Electric Vehicle (HEV) Modelling

In this paper a series-parallel combination of HEV is employed because of its higher efficiency compared to other combinations. The Modelling of HEV is done on MATLAB Simulink platform. The System modelling is based on three sub modelling. One is a control system of HEV, second is modeling of electrical system, and third as modelling of mechanical system. The power train configurations are shown in Figure 4.1.

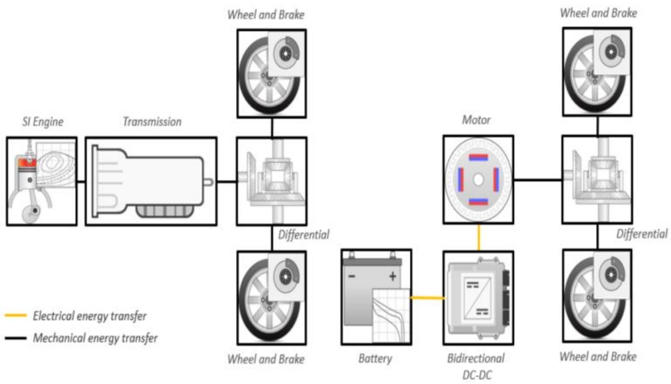

Fig. 4.1 Power Train Configuration of HEV

A. Drive cycles

Different derive cycles with variable speed vs time change can be used to check the performance of the HEV in varied conditions. This variation can be used to assess and compare fuel consumption, power output, pollutant emission of series - parallel hybrid electric machine under different conditions. There are 2 types of drive cycles used to check the response of HEV viz. standard drive cycle and transient cycles. The first represents acceleration at constant speed periods, and the second represents real drive mention in a block diagram Figure 4.2.

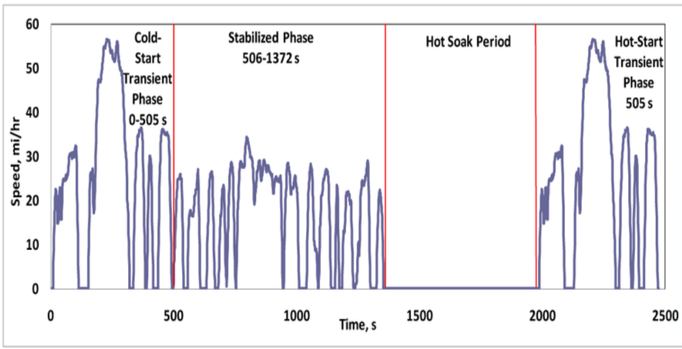

Fig. 4.2 FTP-75 drive cycle

DC link voltage and battery current is complementing each other

V. SIMULATION RESULTS

In this model, series-parallel combination of hybrid electrical vehicle is tested with FTP-75 drive cycle.

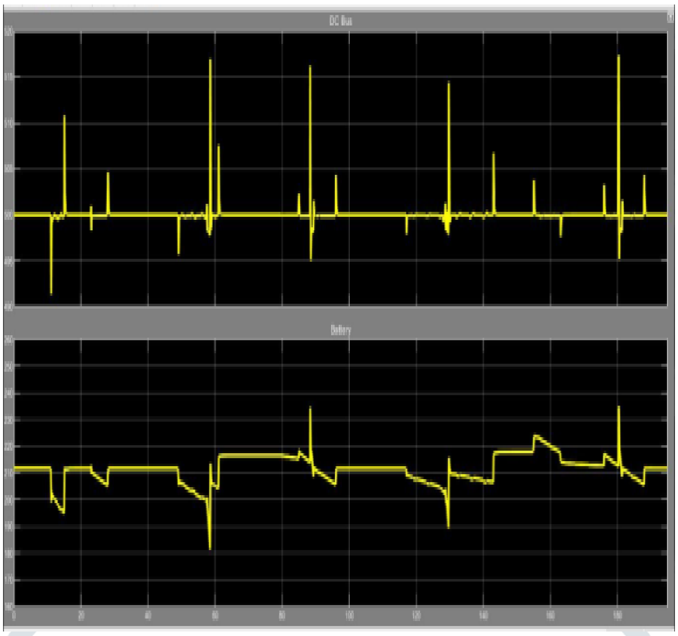

Fig. 5.1 DC link voltage and Battery response.

The simulation results are showing the performance of voltage profile of the EHV, engine speed, motor speed and and battery behavior CORRESPONDING to the drive cycle.

Figure 5.1 represents the response of DC link voltage in the upper section of the figure and battery response is shown in lower section of the figure. It is quite apparent that DC link voltage and Battery current is responding to each other.

In Figure 5.2, Engine speed response is shown. It is also MANIFESTED that the response of the ENGINE is CORRESPONDING to the drive cycle and it is same as transient phase, stabilized phase, hot soak period and hot-start transient phase.

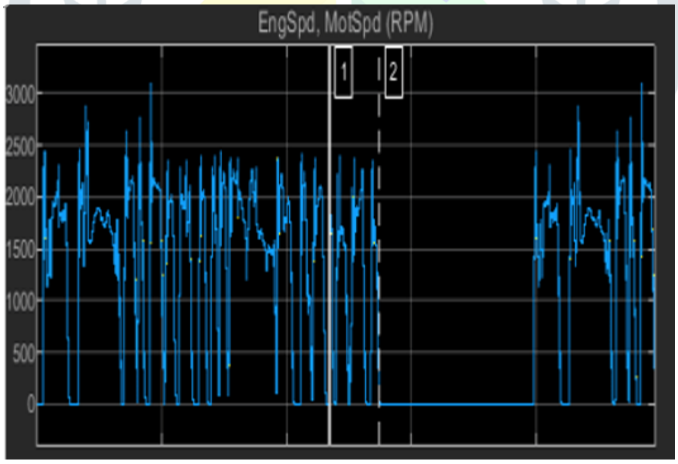

Figure 5.2 engine speed

Figure 5.3 and 5.4 are demonstrating the response of battery current and battery charging status respectively.

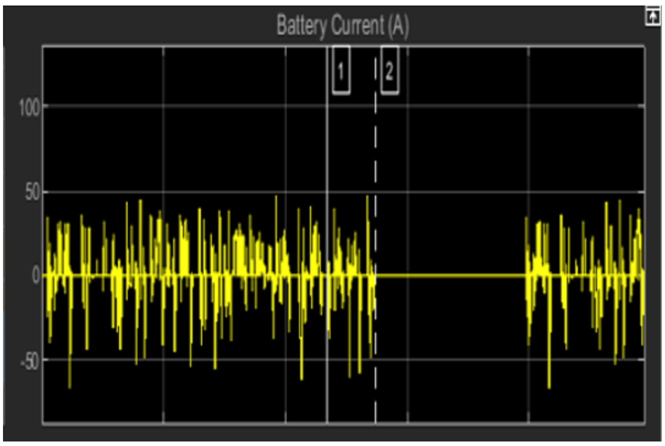

Figure 5.3 Battery current

State of Charge (SoC) is the level of charge. It cannot be measure directly but we can estimate from direct measurement variables in two ways offline and online. There is another term Depth of Discharge (DoD), which means the level of discharge, is just opposite to SoC; 100% means empty, or 0% means full charge.

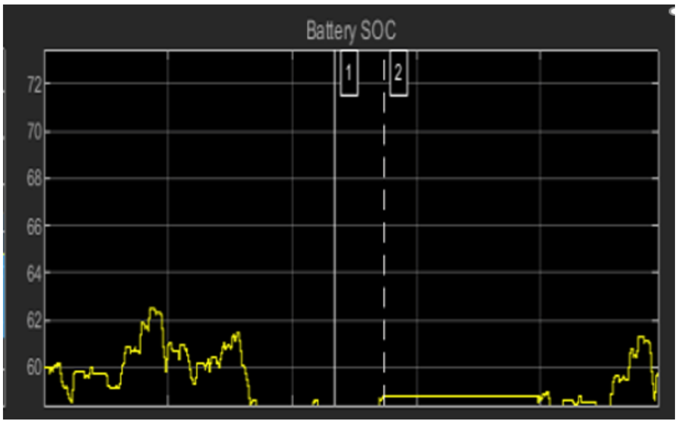

Fig. 5.4 Battery SOC.

It is a little bit different in their working aimed that SoC defines for battery charging whereas DoD is seen when we discuss battery lifetime after repeated use, in above figure 5.4 it can be seen that the value of SOC vary with in a limited value. If the value of SOC is less than 30% in this condition we can drive the vehicle as well as battery will be charge. The battery current and state of charge graph are Shawn in the above figure-5.3, 5.4 where battery peak current varies according to time whereas at the end of the cycle state of charge is about to more than 60%. If the battery state of charge increased beyond 100% so there is no need for generation. DC bus voltage varies around reference voltage which is around 500V and maximum notice voltage is around 517V and minimum voltage 487V. The maximum fluctuation in voltage is around 30V and for the battery it is 55V.

Output powers:

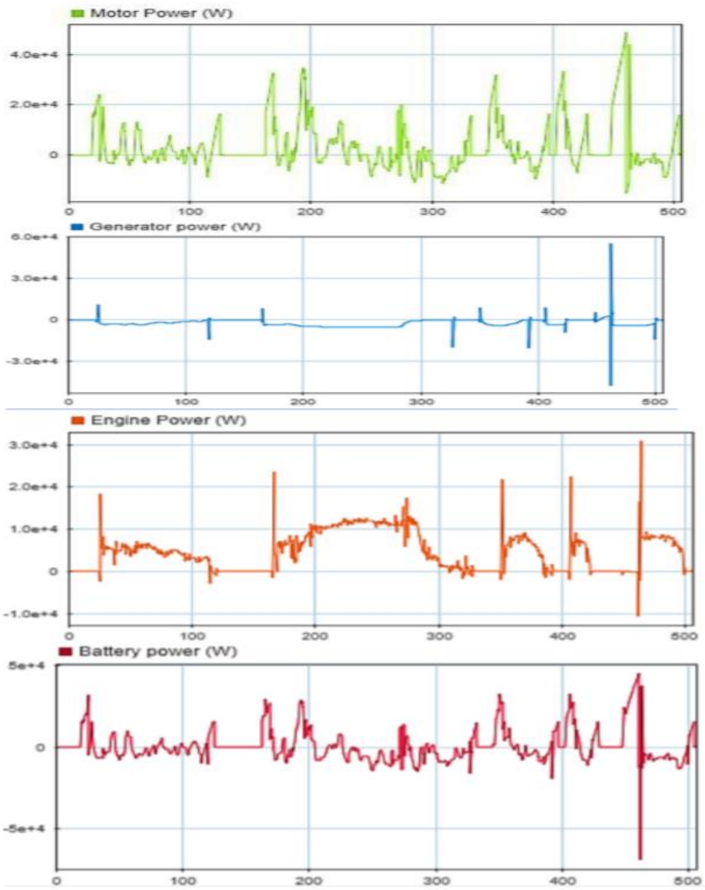

Table-2: Other simulation details

S. NO.	Criteria	HESS
1	Structure	Simple
2	No. of converter	1
3	Maximum DC link voltage(V)	517
4	Minimum DC link voltage(V)	487
5	DC link ripple(V)	30
6	Battery SOC%	62 – 65
7	Maximum battery voltage	235
8	Minimum battery voltage	180
9	Battery ripple voltage (V)	55

VI. Conclusion

This paper describes the working of a series-parallel hybrid electric vehicle with different energy management strategies. in this, we focused on an energy storage system with HESS as discussed earlier. As we know we energy storage systems have lots of characteristics and specifications, With the help of MATLAB, we simulated series-parallel hybrid electrical vehicles. In this configuration, we use different drive cycles for better results. But in this paper, we used FTP75 drive cycle duration 2474second. After that, we can find the ripple of battery current and the ripple of the battery voltage, as shown in the above table-2. With the help of the same software, looking for different strategies for a series-parallel hybrid electric vehicle with 2 energy storage devices, like active cascade 2 parallel converter. By using this we can reduce the ripple of this system.

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