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OPTIMIZATION CONTROL IN HYBRID ELECTRIC VEHICLE FOR ITS ENERGY MANAGEMENT

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Abstract- In electric vehicles, the battery's low life span is the primary concern for manufacturers worldwide as the battery is the only energy source. A hybrid electric vehicle (HEV) consisting of two or more energy sources with proper energy management and power management is the solution for better fuel economy and lower tailpipe emissions. The main scheme of energy management strategy (EMS) is to split energy between these sources to reduce fuel consumption and to attain utmost power utilization. EMS can be Rule Based or Optimization Based Strategy. In this paper, some energy management strategies are employed to determine the output of different energy sources and different EMS is applied to the model to lessen the fuel consumption of vehicle. The simulation for all the strategy is performed by using MATLAB/Simulink.

Keywords: Hybrid Electric Vehicle, Battery, Fuel Cell, Super-Capacitor, Energy Management, Equivalent Fuel Consumption Minimization, Genetic Algorithm.

1. INTRODUCTION

According to several environmentalist, gasoline based vehicle are today’s concern as it can harm the atmosphere very badly. To overcome the disadvantages of conventional vehicles, electric vehicle can be used to maintain the favorable condition. EVs are the cleanest and eco-friendly vehicle. A basic EV has a battery as the main energy source. Battery powered electric vehicles have merits like better energy efficiency and no environment pollution. Major disadvantage of these vehicles are that the battery used in this have low life span, high initial cost, short driving range.

This led to the invention of the HEVs. An HEV can involve battery, fuel cell, super-capacitor and photo voltaic cell as the energy sources. The EV was advanced to attenuate the limitation of both Internal Combustion Engine (ICE) vehicles and the pure battery powered electric vehicle. HEVs can be very effective as it recharges with electricity that costs a fragment of the price of a full tank of fossil fuels. Further HEVs can be categorized as Parallel, Series and Power Split based on which power is supplied to drive train. Energy Management Strategies (EMS) of HEVs is important as it can divide the energy between the different energy sources. EMS is essential to achieve hybridization in the vehicle. Rule-Based and Optimization-Based strategies are the basic two types of EMS for HEVs. These strategies are applied according to the type of vehicle. In this paper, different strategies are applied to the model of electric vehicle to analyze the total power output of the system.

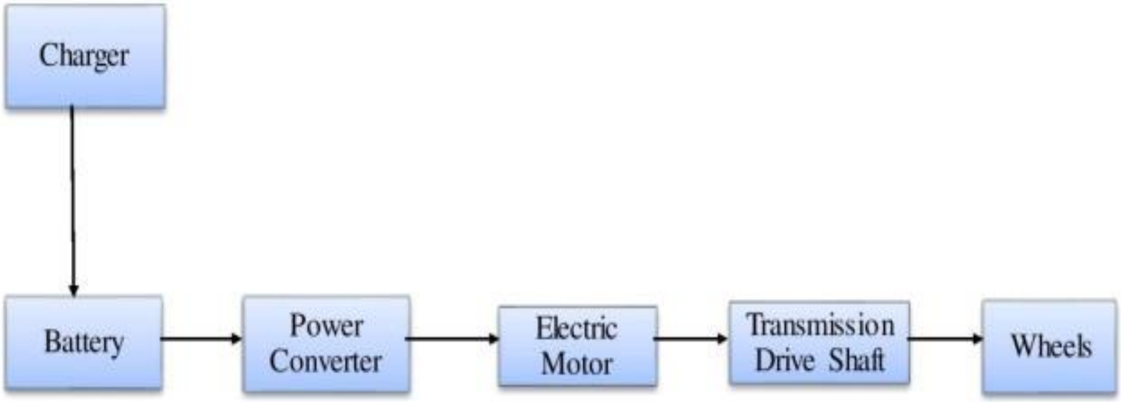

Fig.1.1 Basic Block Diagram of an Electric Vehicle

In ECMS, battery power or energy transforms into the equivalent fuel energy. This transformation can reduce the total fuel consumption. By this, optimal power distribution can be identified instantaneously. To obtain equivalent fuel power, it is required to determine the conversion factor whose value has to be a true value for the effectiveness of the strategy. Although, observing the true value is not a simple procedure since it is mandatory to evaluate power conversion efficiencies for the whole system as well as the charge sustaining approach for battery for the

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predetermined driving cycle. Choosing the aimed torques, speed of the ICE as well as electric motors (EM), the ECMS decides the target gear ratio and load leveling power. The ECMS determines the operating target of the ICE as well as for EMs, which can reduce the fuel power (equivalent) and also determines power demand of the vehicle. Speed range and torque range is also determined by this strategy. Driving Cycle is must information as it can be reflected by equivalence factor.

The classical optimization methods have some limitations which are derived by traditional method. Traditional calculation only determines the local optimal solution for objective function. These calculations are often stuck in local optimal solutions for multi-peak function. Several calculations have high specification precision. Objective function concavity is also present in the system and they don't have any solutions for function such as discrete, random. Optimization methods have some applications like prisoner's dilemma, production scheduling problem. To increase driving distance, to consume less hydrogen, optimization based control strategies are used.

Genetic Algorithm optimization method is introduced to find the equivalent factor S. It can be determined for the specified conditions. The real-time equivalent energy control strategy determines the distribution of the torque in the engine as well as for motor. These are determined for various SOCs. It can fulfill the total power demand of the vehicle. Detailed introduction of Genetic Algorithm is discussed later in the paper.

2. SYSTEM MODELING AND SIMULATION

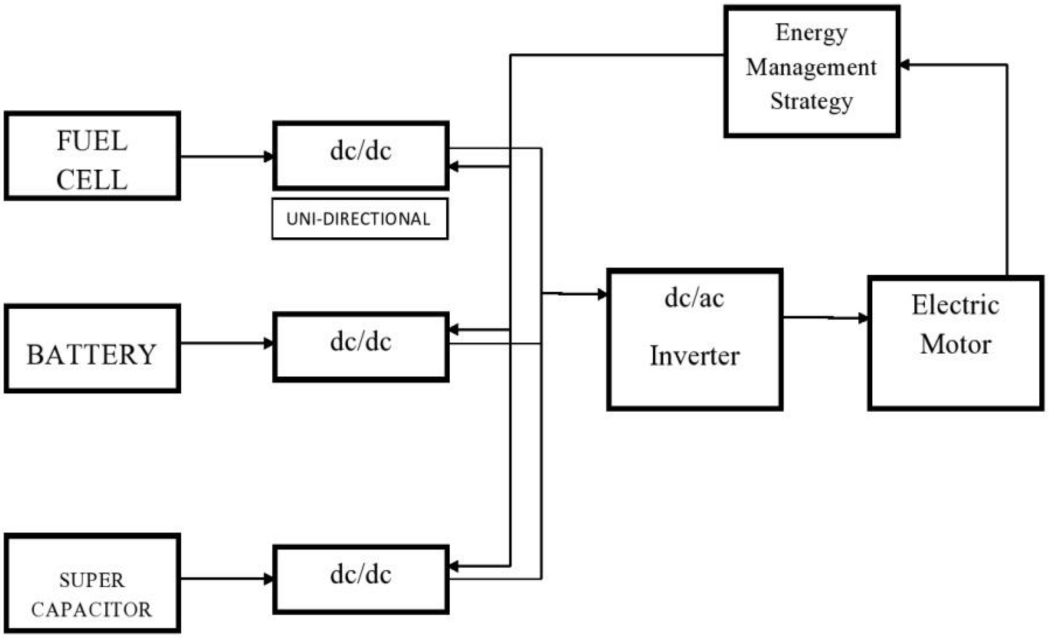


Fig. 2.1 Basic Scheme of the Hybrid Electric Vehicle

2.1 Super-Capacitor

This is a energy variant with high specific energy density (Wh/kg). It also has higher power density (W/kg). It stores less amount of energy in compare with battery but produces power at a higher rate. Super-capacitor is the ratio of charge to the applied voltage.

Table-2.1 Super-Capacitor Block Parameters

Block Parameters	
Rated Capacitance (F)	15.6
Equivalent DC Series Resistance (Ω)	150*e-3
Rated.Voltage (V)	291.6
No. of Series Capacitance	108
No. of Parallel Capacitance	1
Initial Voltage (V)	270
Operating.Temperature (˚C)	25

2.2 Battery

It is an electrochemical cell which changes stored chemical energy in electrical energy. There are three types of batteries used in electric vehicles which are lithium ion, nickel metal hydride, lead-acid. In this research I have used lithium ion battery for simulation purpose.

Table-2.2 Battery Block Parameters

Block Parameters	
Nominal Voltage (V)	48
Rated Capacity (Ah)	40
Initial State of Charge (%)	65
Battery Response Time (s)	20

2.3 Fuel Cell

It is also an electrochemical cell that changes chemical energy or an oxidizing agent into electricity. Types of fuel cells are- Polymer electrolyte membrane fuel cells, direct methanol fuel cells, alkaline fuel cells, Phosphoric acid fuel cells, Molten carbonate fuel cells, Solid oxide fuel cells, And Reversible Fuel Cells.

Table-2.3 Fuel Cell Block Parameters

Block Parameters	
Voltage @ 0A and @1A	52.5 52.46
Nominal Operating Point (I_{nom}, V_{nom})	250 41.15
Maximum Operating Point (I_{end}, V_{end})	320,39.2
Operating Temperature (˚C)	45
Nominal Stack Efficiency (%)	50

2.4 Converter

In this proposed work, various converters are used to convert the voltages at different points. DC-DC converters are mainly used for converting the fixed DC voltage in variable DC voltage. A DC-DC boost converter steps up to the voltage while stepping down the current. A dc-DC buck converter works opposite to boost converter meaning stepping down the voltage. A DC-DC converter changes the DC voltage in AC sinusoidal voltage. A detailed overview of the converters used in the simulation is are as follows-

Table-2.4 FC DC-DC Block Parameters

Block Parameters	
Full Load Current	45
Efficiency @Full and @10% Load	85,10
Response Time (s)	0.1
Load Capacitance (F)	15.6

Table-2.5 DC-DC Boost Block Parameters

Block Parameters	
Full Load Current	45
Efficiency @Full and @10% Load	85,10
Response Time (s)	0.1
Load Capacitance (F)	15.6

Table-2.6 DC-DC Buck Block Parameters

Block Parameters	
Full Load Current	20
Efficiency @Full and @10% Load	80,88
Response Time (s)	0.1
Load Capacitance (F)	$100e^{-3}$

Table-2.7 DC-AC Block Parameter

Block Parameters	
Output Line Voltage (V_{rms})	200
Output Frequency (Hz)	400
Nominal Efficiency (%)	97

One of the methods in Optimization Based strategy is Genetic Algorithm. Genetic algorithm can be stated as the technique which is inspired by the Charles Darwin's theory. This algorithm is based on the natural selection in which the most fitted individual is selected for the reproduction part to resolve the issue for the upcoming or next generation. In Genetic Algorithm, five steps are included to complete the process which are-

Determine the initial Population

- Find Fitness Function
- Selection
- Crossover
- Mutation

To determine the initial population, first a set of individuals has to be defined which is called population. These set of individuals later categorized into parameters or variables. These variables are called as Genes. Later genes are formed as Chromosomes or solution. Fitness function describes the fit level of individual used in the initial population. To be precise it mainly focuses on the fittest individual to perform the algorithm. Selection process is the main part of the algorithm as it decides which individual will pass their genes to the next generation. Crossover step determines the point at which the genes are mated. Mutation mainly focuses on the population to maintain the diversity and to stop premature convergence.

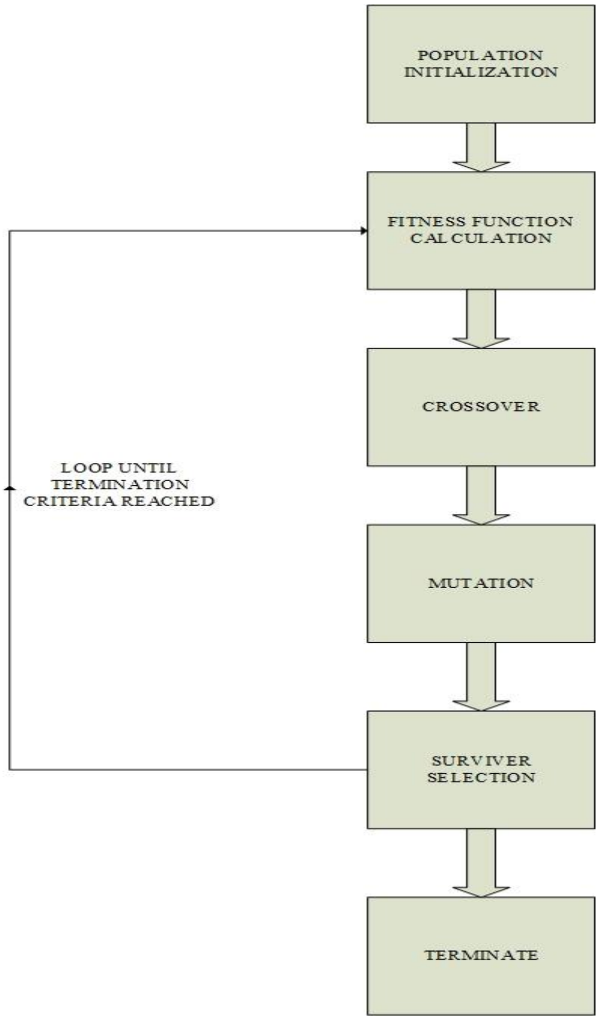


Fig. 2.2 Basic Flow Chart of Genetic Algorithms

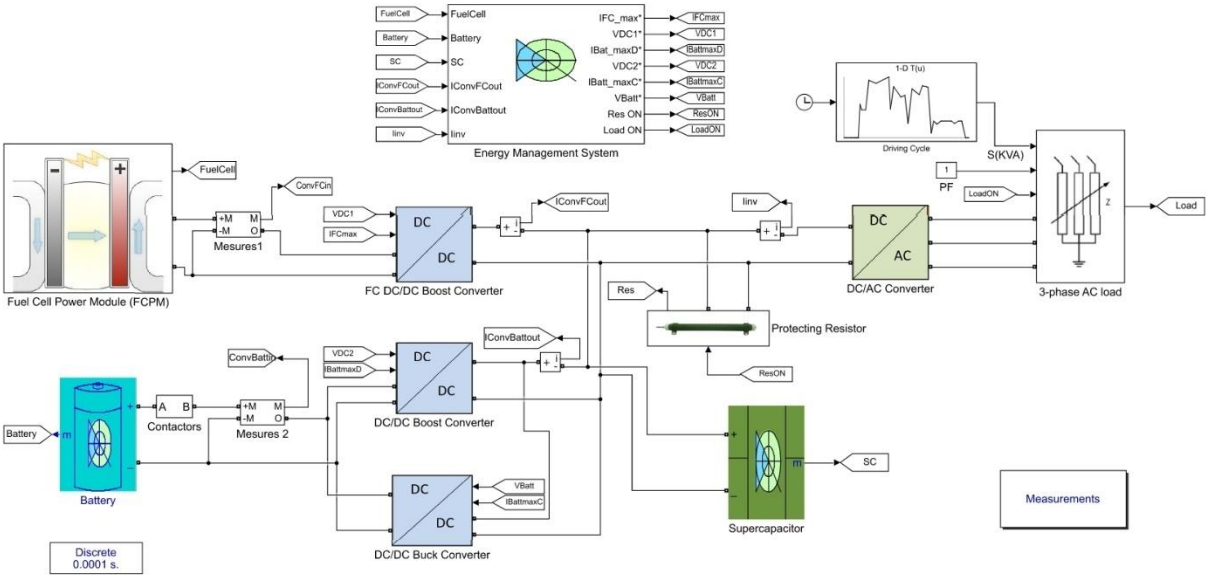
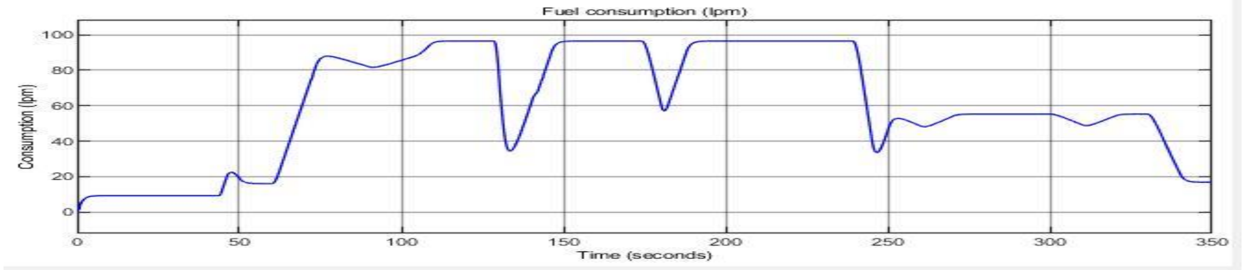


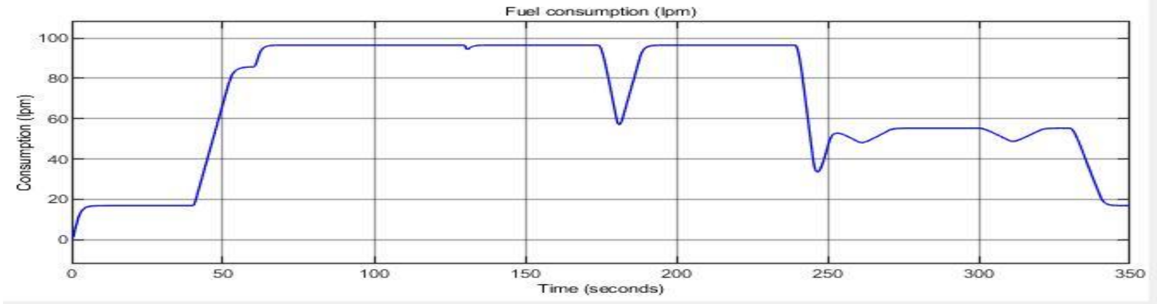
Fig. 2.2 Simulation Model

3. SIMULATION RESULT

For simulation purpose I have applied 350 sec total sample time on the model. By comparing rule based strategy and optimization based strategy on the hybrid model it can be seen that total fuel consumption (lpm) of the vehicle gives variable output for about 100 sec. in rule based strategy while in optimization based strategy it gives almost constant output for the same time. Fig 3.1 shows the comparison between two strategies applied. For the battery voltage output, by comparing the same strategy it can be seen that for rule based strategy battery voltage gives almost constant output while for GA based ECMS battery output gives variable value which means the vehicle battery SOC % is at desired level. It shows the variation in the vehicle which can help reduce the total fuel consumption of the vehicle. Fig 3.2 shows the comparison between two strategies applied. For the ultra capacitor current output, again by comparing the strategies it can be seen that for rule based strategy ultra capacitor current is not showing the variation during the simulation which shows that the capacitor is not sharing the energy with the battery and fuel cell. But in GA based ECMS, it shows the deviation from the initial point. It indicates the energy sharing between the battery, fuel cell and ultra capacitor. Fig. 3.3 shows the comparison between the strategies. Fig. 3.4 shows the total power of the vehicle after applying the strategies. It can be seen from the figure that for rule based strategy, total power of the vehicle is less as compared to the GA based ECMS.

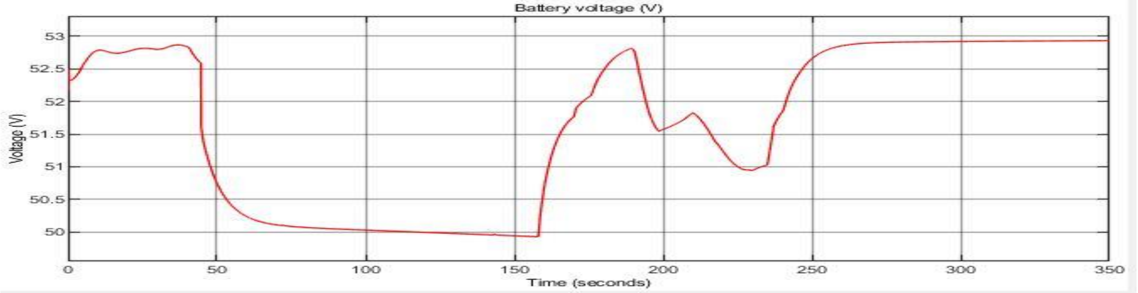


Fuel Consumption with Rule Based

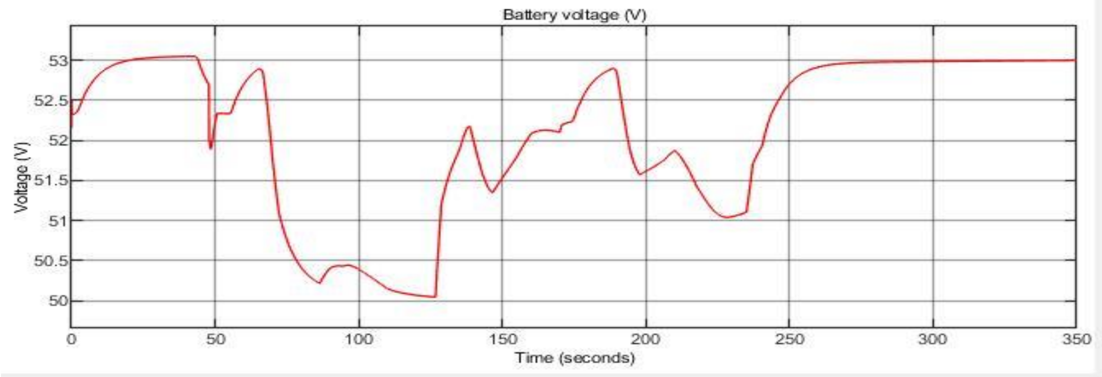


Fuel Consumption with GA-ECMS

Fig.3.1 Fuel Consumption (lpm)

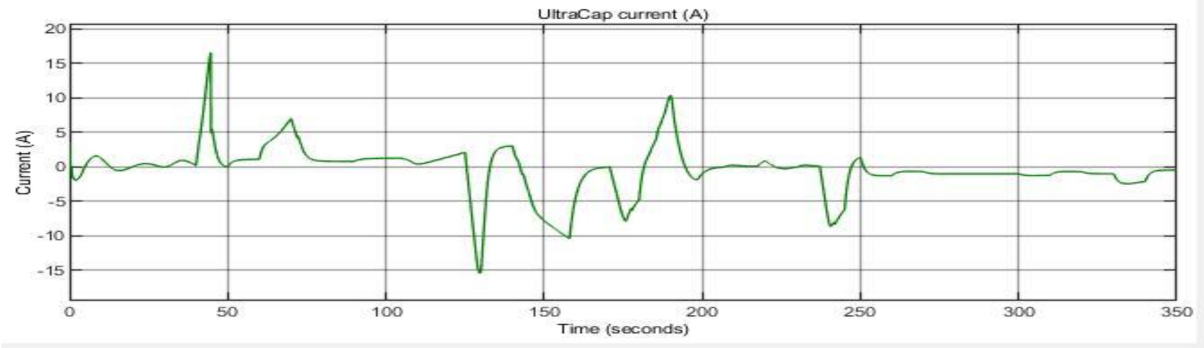


Battery Voltage with Rule Based

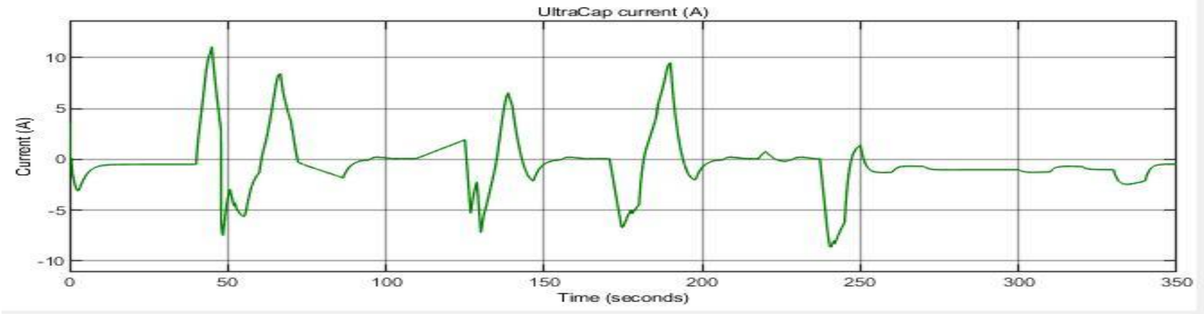


Battery Voltage with GA-ECMS

Fig.3.2 Battery Voltage (V)

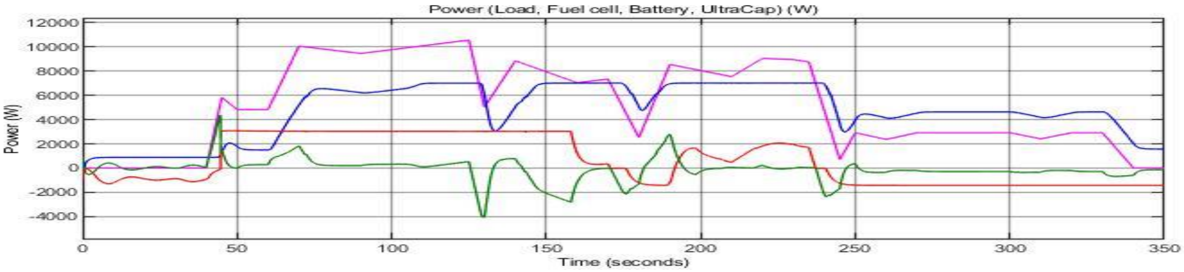


Ultra-Capacitor with Rule Based

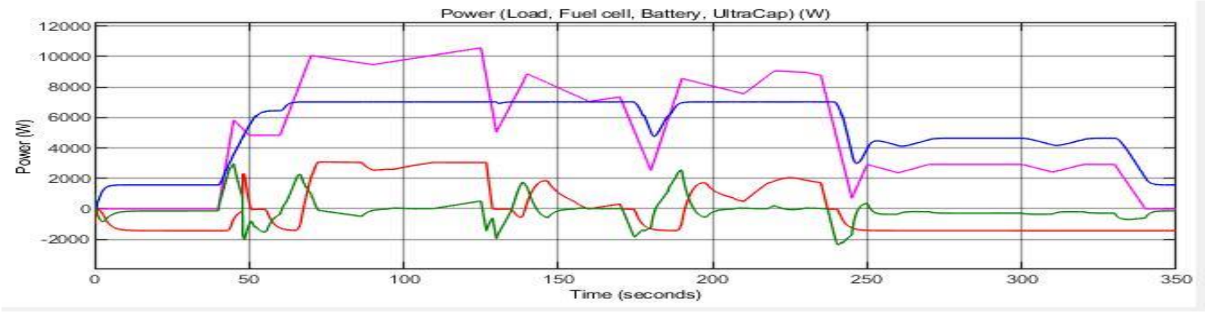


Ultra-Capacitor with GA-ECMS

Fig.3.3 Ultra-Capacitor Current (A)



Power with Rule Based



Power with GA-ECMS

Fig. 3.4 Total Power (W)

CONCLUSION

Rule based and optimization based strategies for energy management has been applied to the simulink model. Main objective of the simulation is to reduce the total fuel consumption of the vehicle which can be achieved by applying genetic algorithm to the model. Fuel cell electric vehicles (FCHEV) are drove by hydrogen which can emit water and air only. Super-capacitor is used to provide the required high power to the vehicle to lessen the load variation on fuel cell and battery. By comparing the strategies it can be seen that GA-ECMS gives the better results for fuel consumption minimization purpose.

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