Energy management of hybrid electric vehicle

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Abstract:

Hybrid Electric Vehicles (HEVs) have become a viable technology as the global automobile industry looks for novel ways to lower greenhouse gas emissions and improve fuel efficiency. When it comes to maximizing the use of various power sources, such as internal combustion engines and electric motors, energy management in hybrid electric vehicles (HEVs) is essential. Maintaining maximum efficiency while balancing the power supply and demand is the main goal of energy management in HEVs. This entails coordinating a number of subsystems, including the energy storage system, electric motor, and internal combustion engine.

Keywords: Electric vehicle, Battery management system, BMS.

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1. **Introduction:** In the field of sustainable transportation, hybrid electric vehicle (HEV) energy management is a crucial and evolving frontier. Focused on minimizing greenhouse gas emissions and the environmental impact of the automotive industry, hybrid electric vehicles (HEVs) have become a game-changer by combining the best features of internal combustion engines and electric propulsion systems. Fundamentally, HEV energy management is the complex coordination of power allocation among these various sources, with the ultimate objective of maximizing fuel economy, reducing emissions, and improving overall vehicle performance[1]-[4]. Due to this complex problem, creative control algorithms and strategies have been created, enabling smooth power source changes and previously unheard-of levels of efficiency and environmental responsibility in vehicle operation. In this context, the energy management of HEVs transcends mere automotive engineering; it represents a paradigm shift that could redefine the future of mobility and play a pivotal role in achieving sustainability goals on a global scale. This introduction sets the stage for an in-depth exploration of the intricacies, advancements, and potential ramifications of HEV energy management in the modern age of transportation[5]-[8].

2. **Components of Hybrid Electric Vehicle:** To achieve maximum fuel efficiency and lower emissions, a hybrid electric vehicle (HEV) combines an internal combustion engine (ICE), one or more electric motors, and an energy storage system (ESS). Electric motors offer electric-only propulsion, support the internal combustion engine (ICE) and function as generators during regenerative braking. The ICE, which is typically powered by gasoline or diesel, supplies power as needed. In addition to storing energy for electric motor operation, the ESS—typically a battery pack—captures regenerative energy. electricity electronics control energy flow by switching between AC and DC, and electricity is effectively distributed via a specialized transmission system[9],[10]. Power distribution is optimized via sophisticated controllers and software algorithms that synchronize component operation. When braking, kinetic energy is captured by a regenerative braking system and stored for future use. In an effort to avoid overheating, thermal management systems control component temperatures. The range of electric-only driving for Plug-in Hybrid Electric

Vehicles (PHEVs) can be increased by external charging via charging ports and an energy management interface[11]-[15]. In hybrid electric vehicles, this component integration is crucial to maximizing efficiency and reducing environmental effect[16].

3. **Energy Management Strategies:** "Energy Management Strategies" are the cornerstone of efficient and sustainable operation in hybrid electric vehicles (HEVs). As the global automotive landscape undergoes a profound shift towards reduced emissions and enhanced fuel economy, the development and implementation of effective energy management strategies have become paramount[17]-[19]. These strategies encompass a spectrum of techniques and algorithms aimed at optimizing the utilization of both internal combustion engines and electric propulsion systems. By intelligently coordinating power distribution and transitions between these sources, energy management strategies play a pivotal role in improving vehicle performance, reducing environmental impact, and ensuring optimal fuel efficiency. This section delves into the core of HEV technology, exploring various approaches to energy management, from rule-based control to predictive algorithms, shedding light on their applications and their potential to revolutionize the automotive industry[20]-[22].

3.1 Rule-Based Control: "Rule-Based Control" is a fundamental approach to managing the energy and power distribution in hybrid electric vehicles (HEVs). In the pursuit of improved fuel efficiency and reduced emissions, this method relies on a set of predefined rules and decision criteria to determine when and how the internal combustion engine and electric motor should operate. Unlike complex optimization algorithms, rule-based control provides a straightforward and real-time means of balancing power demands. This section explores the principles, advantages, and limitations of rule-based control in the context of HEVs, shedding light on its practical applications and its role in achieving sustainable and environmentally responsible transportation solutions.

3.2 Optimization-Based Control:

"Optimization-Based Control" represents a sophisticated and data-driven approach to managing the intricate energy dynamics within hybrid electric vehicles (HEVs). In an era characterized by an urgent need for reduced emissions and increased fuel efficiency, this method leverages advanced algorithms and mathematical optimization techniques to make real-time decisions about the operation of internal combustion engines and electric motors. Optimization-based control seeks to maximize vehicle performance by constantly evaluating and adjusting the power distribution. This section delves into the intricacies of optimization-based control in HEVs, highlighting its capacity to finely tune power management for optimal efficiency, and its potential to revolutionize the landscape of environmentally responsible transportation[15].

3.3 Predictive Control: "Predictive Control" is an innovative and forward-thinking approach to energy management in hybrid electric vehicles (HEVs). In the context of today's pressing concerns regarding emissions and fuel efficiency, predictive control leverages advanced algorithms and real-time data to make proactive decisions about when and how internal combustion engines and electric motors should operate. This method takes into account factors such as driving conditions, traffic patterns, and terrain, predicting future power demands and optimizing power distribution accordingly. In this section, we delve into the principles and applications of predictive control in HEVs, highlighting its potential to significantly enhance fuel efficiency, reduce environmental impact, and contribute to a sustainable and intelligent future for transportation[18]. Hybrid Electric Vehicle Simulink Model Shown in fig. 1.

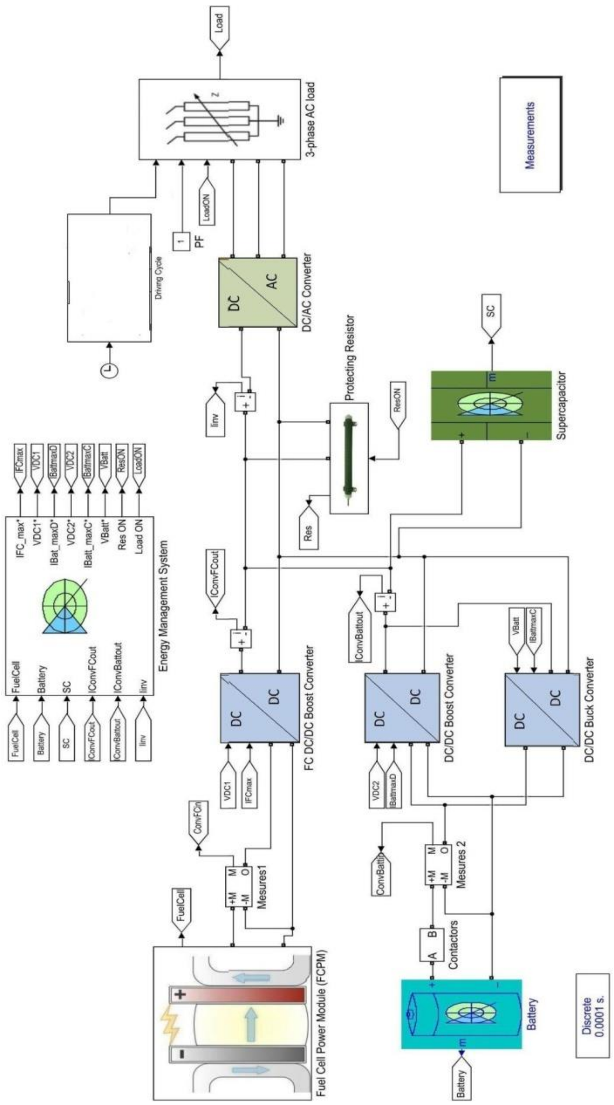


Fig.1: HybridElectricVehicleSimulinkModel

4. Regenerative Braking and Energy Recovery:

5. Results and Discussion: The simulation of a hybrid electric vehicle with an energy management system is presented in this chapter. MATLAB/Simulink was used for the simulation analysis. This research work is primarily concerned with reducing the vehicle's fuel usage. Electric vehicles are growing in popularity right now since they can lessen pollution. Sometimes the vehicle's battery cannot supply the amount of electricity needed by the load. Super capacitors and fuel cells can be utilised to get around this. Super capacitor can give the battery an extra charge-discharge cycle[9]. A rule-based and optimization-based technique has been applied to the vehicle's energy management. For the purpose of minimising fuel usage under various strategies, discussion and analysis are conducted.

Two distinct energy management strategies have been used on the model to reduce the fuel consumption in electric vehicles and compared. They are listed below.

I. Battery, supercapacitor, and fuel cell hybrid electric vehicle performance analysis with rule-based strategy.

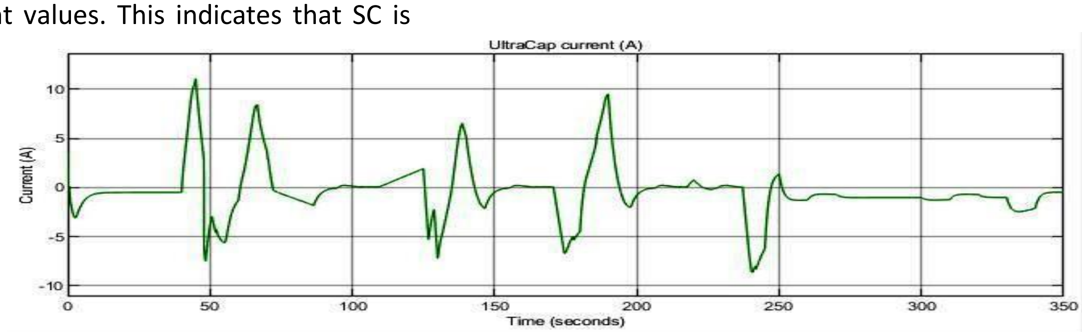
II. Battery, supercapacitor, and fuel cell hybrid electric vehicle performance analysis A-Ecms.

III. Comparison of implemented Ems power output.

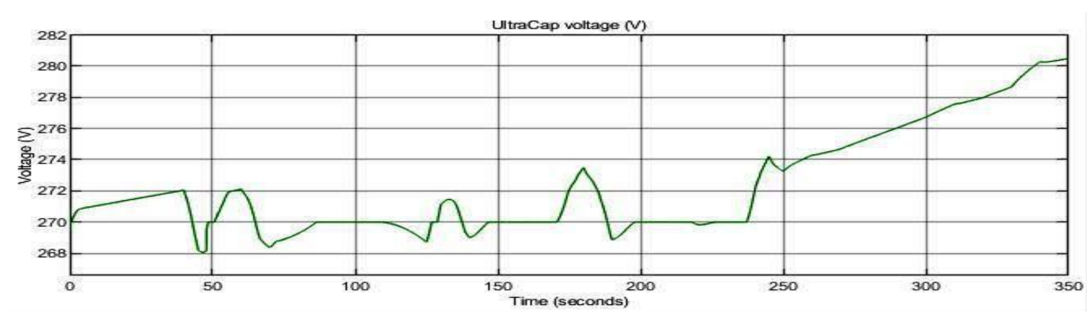
5.1 Super Capacitor

The smallest value of the super capacitor current, which is -7.3219A, is obtained when the approach is applied to the model. The super capacitor's maximum current value is 11.1923A. As observed in fig 2(a), the value is frequently changing as a result of current values. This indicates that SC is giving the hybrid model the charging and discharging characteristics. Fig. The Super capacitor current is shown in fig 2(a).

Model super capacitor voltage yields a minimal value of 268.4121V when strategy is applied to it. 282.01521V is the highest possible value of the super capacitor voltage. It is evident from fig. 2(b) that the super capacitor's voltage varies between 268V and 274V. The SC voltage increases to 281V at 248 seconds. The Super capacitor voltage is depicted in Fig. 2(b).



(a)SuperCapacitorCurrent (A)



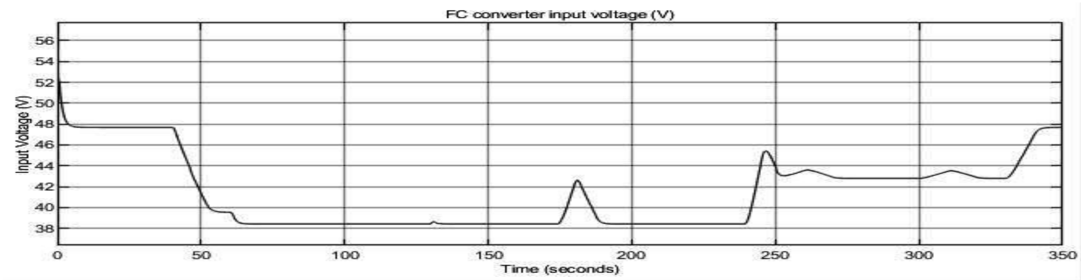
(b)Super Capacitor Voltage (V)

Fig.2:SuperCapacitor (ECMS)

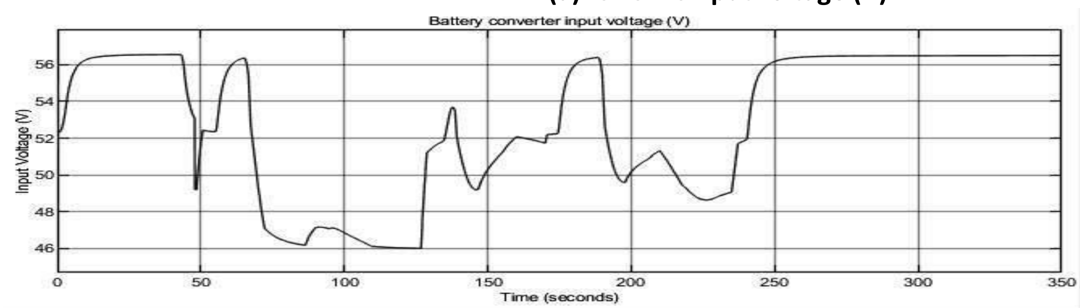
5.2 Converter Voltages

The minimal input voltage for an FC converter when strategy is used on the model is 39.2414V. The maximum input voltage for the FC converter is 54.3867V. Up to 48 seconds, this voltage remains constant. After around 23 seconds, it starts to decline. It doesn't change from 60 seconds to 240 seconds. It then outputs a variable value. Fig. The input voltage of FC DC-DC converters is displayed in fig. 3(a).

Battery converter's minimum input voltage, when strategy is used on the model, is 46.1283V. The battery converter's maximum input voltage is 56.6589V. Within the range of 48 to 250 seconds, this voltage fluctuates between 46 and 56 volts. The input voltage of the battery DC-DC converter is depicted in Fig. 3(b).



(a)FCDC-DCInputVoltage (V)



(b)Battery Converter Input Voltage (V)

Fig.3 ConverterVoltage(ECMS)

5.3 Power Output of the Vehicle under Different Strategies

A. The power output for the rule-based strategy SMCS is depicted in the figure. 4. For the battery, super capacitor, fuel cell, and load, it displays varying power. 3125 W is the maximum battery power. The 10558 W maximum super capacitor power. The overall load power is 7125W, while the highest fuel cell power is 4136W. The vehcile uses 93.45872 lpm of fuel in total while using this method. This method minimises the losses seen in the CPCS. The optimization strategy reduces energy loss in this strategy.

B. The power output for the optimization-based ECMS technique is depicted in

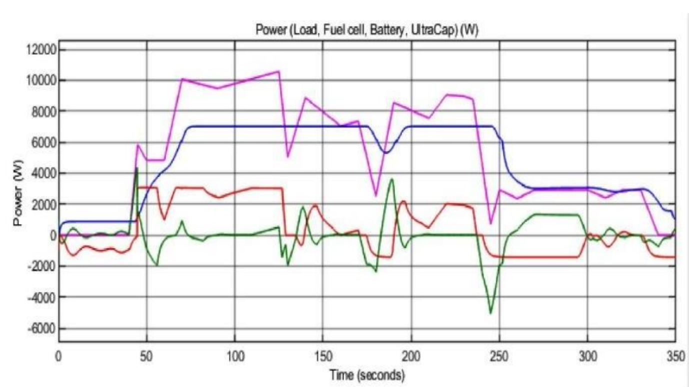


Fig.4 :Power Output of Rule Based

fig. 5 shows that 3492W is the maximum battery power. 11518W is the maximum super capacitor power. Fuel cells have a maximum power of 3923W, and the total power of the load is 7351W. The vehcile in GA-ECMS uses 88.2459 lpm of fuel in total. Another tactic is also used on the model to aid in understanding the ECMS optimization process.

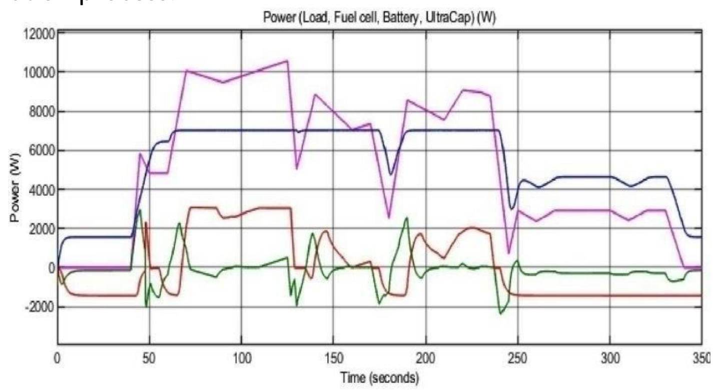


Fig.5 :Power Output of ECMS

The aforementioned figures show that the total fuel consumption is reduced by 10lpm by using GA-ECMS. The simulation shows that a super capacitor is superior to a battery and a fuel cell as an energy storage device for a vehicle since it can store a greater amount of energy.

6. **Conclusion:** The energy management of hybrid electric vehicles (HEVs) holds immense promise as a transformative technology within the automotive industry. The extensive exploration of HEV components, energy management strategies, and the dynamic challenges faced in this paper underscores the critical role that these vehicles play in reducing emissions and enhancing fuel efficiency. The innovative synergy of internal combustion engines and electric propulsion systems, coupled with advanced control algorithms, presents a compelling pathway towards sustainable transportation. As we stand on the cusp of a new era in mobility, the lessons learned from HEV energy management are not just confined to the realm of automotive engineering; they transcend to address broader environmental and societal goals. By continually refining energy management strategies and adapting to emerging technologies, HEVs have the potential to shape a cleaner, more efficient, and environmentally responsible future for transportation on a global scale.

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