CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, a broad literature survey on hybrid electric and plug-in hybrid electric vehicle research is presented. The survey emphasis vehicle modeling and simulation, power and energy management, energy storage devices, propulsion systems and influence of driving cycle that affect the overall efficiency and fuel economy. The survey also focused on economic and emission analysis.

2.2 MODELING AND SIMULATION

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. 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
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.

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.

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.

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. 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.

Kuen-Bao (2008) described the mathematical modelling, analysis and simulation of a novel hybrid powertrain used in a scooter. 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.

2.3 CONTROL SYSTEM

The effectiveness of fuel consumption depends not only on vehicle design but also on the control strategy used. The control strategy provides a dynamic control of the vehicle to ensure the best utilization of the onboard energy resources for the given operating conditions. So, the energy management strategy is extremely important to decide how and when energy will be provided by various sources of PHEV.

In 1999, AVL Company proposed a hybrid system that used a 50 cc carburetted lean-burn two-stroke engine with a 0.75 kW electric motor mounted on the engine crankshaft mainly to provide increased torque during acceleration.
Su-Hau et al (2004) focused on the highly efficient energy usage of the battery energy and proposed an integrated management system for electric motor. This integrated management system includes the power-saving controller, energy management subsystem and some hardware protection strategies. The energy management system acts as a supervisor to manage all the events about the battery energy, including the residual capacity estimation and regenerative braking operation.

David and Sheng-Chung (2004) proposed new parallel-type hybrid-electric-power system comprises an engine’s energy distribution and a torque-integrated mechanism (specifically including an engine, a motor/alternator, a CVT device, and PCM as well as a 3-helical gear set). To let the engine achieve maximum thermo-efficiency with minimum emissions, the servomotors adjust the diameter size of the pulley to control the engine output for the final power-output axle and the alternator. The system is applied with a stable engine-load to maximize operating performance. The vehicle is driven by the motor alone in the light-duty mode. Meanwhile, in the medium-duty mode, power comes from the engine, with extra energy being used for battery charging. Finally, in the heavy duty mode, both the engine and motor together power the vehicle. The engine output is fixed, but the motor output power can be controlled.

Wenguang et al (2005) presented an approach to control powertrain of series hybrid electric vehicles. A formulation of the system equations and controller design procedure were proposed by them. They also proposed a new switching algorithm for the power converter for motor torque and motor flux control. The sliding mode method is applied to excitation winding control in synchronous generator to achieve the desired current distribution in powertrain.
Yimin and Mehrdad (2006) introduced a speed and torque coupling hybrid drivetrain. In this drivetrain, a planetary gear unit and a generator/motor decouple the engine speed from the vehicle wheel speed. Also, another shaft-fixed gear unit and traction motor decouple the engine torque from the vehicle wheel torque. Thus, the engine can operate within its optimal speed and torque region, and at the same time, can directly deliver its torque to the driven wheels. They also discussed the fundamentals architecture, design, control, and simulation of the drivetrain. Simulations show that the fuel economy in urban and highway driving cycles can be greatly improved.

Kuen-Bao and Tsung-Hua (2006) incorporated a mechanical type rubber V-belt, continuously-variable transmission (CVT) and chain drives to combine power of the two power sources, a gasoline engine and an electric motor in hybrid power system. The system uses four different modes in order to maximize the performance and reduce emissions: electric-motor mode; engine mode; engine/charging mode; and power mode. The main advantages of this new transmission include the use of only one electric motor/generator and the shift of the operating mode accomplished by the mechanical-type clutches for easy control and low cost. Kinematic analyses and design are achieved to obtain the size of each component of this system. A design example is fabricated and tested.

Markel and Simpson (2007) discussed the battery power and energy requirements for grid-charged parallel hybrid electric vehicles with different operating strategies. First, they considered the traditional all-electric range based operating concept and shown that this strategy can require a larger, more expensive battery due to the simultaneous requirement for high energy and power. They then proposed an alternative electric-assist operating concept for grid-charged HEVs to enable the use of a smaller, less costly battery.
However, this strategy is expected to reduce the vehicle efficiency during both charge-depleting and charge-sustaining operation.

Zhangcheng et al (2007) presented a novel approach to the problem of power control strategy of series hybrid electric vehicle. They defined three modes of operation and a cost function. To determine which operation mode should be chosen during driving cycles they generated a classifier using support vector machine (SVM). They claimed that their approach does not need any models of devices and needed less computational time. The control strategy was based on inputs from road situation data, battery state-of-charge data and vehicle speed data. Their simulation studies showed the feasibility of the approach.

Daniel (2007) designed, developed and implemented a series hybrid electric vehicle. Though he proposed the architecture as hybrid electric vehicle architecture, he showed that the vehicle runs well in the electric mode and left the hybrid conversion as future expansion. Before developing the hardware part, he did a simulation using PSCAD/EMTDC and validated the simulated results using the hardware he developed.

Gonder and Markel (2007) analysed the energy management strategy for the operation of hybrid electric vehicles. They summarised three potential energy management strategies and compares the implications of selecting one strategy over another in the context of the aggressiveness and distance of the duty cycle over which the vehicle will likely operate. The particular operating strategy employed during the charge-depleting mode will significantly influence the component attributes and the value of the PHEV technology.

Yimin and Mehrdad (2008) discussed the design and control methodology of plug in hybrid electric vehicle. Their design methodology
focused on battery energy and power capacity design. They tried with Ni-MH and Li-ion batteries. Also their control strategy focused on all-electric range and charge-depletion range operations. A constrained engine on and off control strategy was discussed for charge-sustained operation. The simulation results they performed for passenger car indicated that significant amount of fuel can be displaced by electric energy.

Emadi et al (2008) focused more on power electronics as an enabling technology for the development of plug-in hybrid electric vehicles and implementing the advanced electrical architectures to meet the demands for increased electric loads. A brief review of the current trends and future vehicle strategies and the function of power electronic subsystems are described. The requirements of power electronic components and electric motor drives for the successful development of these vehicles are also presented.

2.4 ELECTRIC PROPULSION AND ENERGY STORAGE DEVICE

In the area of propulsion motor and other motor control technologies, methods to eliminate speed/position sensors, inverter current sensors, etc., have been under investigation for several years. The technological challenges for the electric motors will be light weight, wide speed range, high efficiency, maximum torque and long life.

Most hybrid hardware subsystems and components with exception of energy storage devices have been matured to an acceptable level efficiency performance and reliability. As per the studies, the energy stored in the HEV storage unit is much smaller than that in the EV unit. It is also clear that the power capability of the batteries designed for HEVs is much higher than those designed for EVs. However, batteries for plug-in hybrid electric vehicles
require both high energy density and high-power capability based on the driving requirements. The other significant technical challenges include higher initial cost, cost of battery replacement, added weight and volume, performance and durability.

Mehrdad et al (1997) presented a design methodology for EV and HEV propulsion systems based on the vehicle dynamics. This methodology is aimed at finding the optimal torque-speed profile for the electric powertrain. The study reveals that the extended constant power operation is important for both the initial acceleration and cruising intervals of operation. The more the motor can operate in constant power, the less the acceleration power requirement will be. Several types of motors are studied in this context. It is concluded that the induction motor has clear advantages for the EV and HEV at the present. A brushless dc motor must be capable of high speeds to be competitive with the induction motor. However, more design and evaluation data is needed to verify this possibility. The design methodology was applied to an actual EV and HEV to demonstrate its benefits.

Bartlomiej et al (2003) provided the evaluation of driving power and energy requirements for automotive vehicle. A survey of most promising applications of electric and hybrid vehicles in cities with commercial line solutions was given. Evaluation of vehicle’s energy, when is referred to urban driving cycles, reflects an important diversification of the average and maximal power requirements. Simulation results of a small car equipped with advanced fuel cell converter and supercapacitor storage bank have indicated the power flow between these sources at normalized urban driving conditions.

Andrea et al (2005) described the energy budgeting for the EV and the HEV, which shows that the HEV is today competitive alternative to the ICE vehicles. A series hybrid technology is built and tested on a prototype. The range extender and power-assist mode of operation were tested and the
results reported. The solution was designed to meet very low production costs without compromising too much on the efficiency. The cost of the additionally needed DC-DC converter between the battery and the DC link is more than compensated as it allows to keep the battery at a smaller size without having to reduce the capacity to very small and hardly controllable capacities.

Rajeswari et al (2006) studied the capacity of the energy storage system i.e. the battery in a hybrid vehicle. Various tests on the discharge characteristics, including study of Ohmic resistances under various cases was carried out for a separate battery as well as a battery used in a hybrid vehicle and the former was found to have greater impedance while cycling. The relevance would be the battery selection and analysis, charging modes and technologies.

Markel and Simpson (2006) proposed that, plug-in hybrid electric vehicle technology holds much promise for reducing the demand for petroleum in the transportation sector. Its potential impact is highly dependent on the system design and the energy storage system. They discussed on the design options including power, energy and operating strategy as they relate to the energy storage system. They studied the design options including power, energy, and operating strategy as they relate to the energy storage system. Expansion of the usable state-of-charge window will dramatically reduce cost but it will be limited by battery life requirements. Increasing the battery power capability will provides the ability to run all-electrically more often but it will increase the cost. Increasing the energy capacity from 20-40 miles of electric range capability provides an extra 15% reduction in fuel consumption but also nearly doubles the incremental cost.

Wong et al (2006) studied the advanced batteries for HEV and PHEV applications and investigated the lifecycle costs of different types of
vehicles quantitatively. General equations were developed to describe the performance requirements and cost of all subsystems in vehicles. Their conclusions suggest that lead-acid batteries can be manufactured to meet the vehicle life cycle requirements of HEVs and PHEVs. The life cycle cost of HEVs is the lowest among CVs, PHEVs, HEVs. The batteries of PHEVs should be sized according to the driving habits of the drivers.

O’Keefe and Markel (2007) have presented a comparison of the costs (vehicle purchase costs and energy costs) and benefits (reduced petroleum consumption) of PHEVs relative to hybrid electric and conventional vehicles. A detailed simulation model is used to predict petroleum reductions and costs of PHEV designs compared to a baseline midsize sedan. A simple economic analysis is used to show that high petroleum prices and low battery costs are needed to make a compelling business case for PHEVs in the absence of other incentives.

Markel (2007) incorporated platform engineering steps including, reduced mass, improved engine efficiency, relaxed performance, improved aerodynamics and rolling resistance can impact both vehicle efficiency and design. Simulations have been completed to quantify the relative impacts of platform engineering on conventional, hybrid and PHEV powertrain design, cost and consumption. The application of platform engineering to PHEVs reduced energy storage system requirements by more than 12%, offering potential for more widespread use of PHEV technology in an energy battery supply-limited market. Results also suggest that platform engineering may be a more cost-effective way to reduce petroleum consumption than increasing the energy storage capacity of a PHEV.

Eckhard et al (2007) characterises the associated vehicle attributes and in particular, the various levels of hybrids. New requirements for the electrical storage system are derived, including: shallow-cycle life, high
dynamic charge acceptance particularly for regenerative braking and robust service life in sustained partial-state-of-charge usage. Advanced AGM batteries may be considered for mild or even medium hybrids once they have proven robustness under real-world conditions, particularly with respect to cycle life at partial-states-of-charge and dynamic charge acceptance. For the foreseeable future, Ni-MH and Li-ion are the dominating current and potential battery technologies for higher-functionality HEVs. Li-ion, currently at development and demonstration stages, offers attractive opportunities for improvements in performance and cost. Opportunities and challenges for potential battery pack system suppliers are discussed.

Bhoopal et al (2009) discussed the development of power electronics and real time control technology for hybrid electric vehicle. These include AC drives with real time torque control, compact and rugged induction motors, auxiliary electric circuits etc. He developed a set of DSP based circuits for AC induction motor drives for EVs. It provides torque control for propulsion and power control for generation and battery charging. The propulsion motor is controlled by a fixed point DSP based controller, which provides torque control based on driver commands. The IC engine is coupled to a generator, whose output is rectified to get the DC voltage. A dashboard, with microcontroller based circuits, provides the driver interface. The various controllers are interlinked through a serial network.

Bhim Singh and Sanjeev Singh (2009) presented state-of-the-art permanent magnet brushless DC (PMBLDC) motor drives with an emphasis on sensorless control of these motors. The PMBLDCM drives are suitable for many applications; however, the choice of the motor (i.e. rotor configuration), control scheme (i.e. sensorless or with sensors) and controller topology depends on the accuracy, cost, complexity and reliability of the system. ASICs are one step in the direction of low cost controllers and many more
such ICs with cost effective solutions will be developed in the near future. A customer can select a PMBLDCM drive with their desired features, however, there is a tradeoff between the number of parameters (e.g. sensorless or with sensors, accuracy, complexity, reliability and cost of controller). It is hoped that this investigation on PMBLDCM drives will be a useful reference for users and manufacturers.

Divya and Jacob (2009) discussed the present status of battery energy storage technology and methods of assessing their economic viability and impact on power system operation. Further, a discussion on the role of battery storage systems of electric hybrid vehicles in power system storage technologies had been made. As far as the battery technology is concerned, in future there will be significant development in reducing the battery cost and improving their reliability. The future of large scale batteries extensively designed for using in electricity grid is also quiet promising. Finally, they suggest a likely future outlook for the battery technologies and the electric hybrid vehicles in the context of power system applications.

John et al (2010) explored two aspects of market for plug-in hybrid electric vehicles: (1) PHEV performance goals and (2) the abilities of present and near-term battery chemistries to meet the resulting technological requirements. They summarized evidence stating that battery technologies do not meet the requirements that flow from three sets of influential PHEV goals due to inherent trade-offs among power, energy, longevity, cost, and safety. However, they also shown that part of this battery problem is that those influential goals are overly ambitious compared to goals derived from consumers’ PHEV designs. They elicited PHEV designs from potential early buyers among U.S. new car buyers; most of those who are interested in a PHEV are interested in less technologically advanced PHEVs than assumed by experts. Using respondents’ PHEV designs, they derived the peak power
density and energy density requirements and shown that current battery chemistries can meet them.

Ismail et al (2010) presented a design procedure for an internal combustion engine hybrid electric propulsion system. The choice of suitable components is the key issue in the design procedure of a hybrid electric vehicle. Different selections and different sizing choices highly influence the overall performance expected from the vehicle. Maximum cruise speed, acceleration performance, gradability and energy recovery are defined as the key parameters of the design procedure. Finally, a case study was also presented to demonstrate the propulsion system design procedure of a parallel hybrid electric vehicle.

Jeremy and Ahmad (2011) took a first step toward an assessment by estimating the impact of battery second use on the initial cost of PHEV/EV batteries to automotive consumers and exploring the potential for grid-based energy storage applications to serve as a market for used PHEV/EV batteries. It was found that although battery second use is not expected to significantly affect today’s PHEV/EV prices, it has the potential to become a common component of future automotive battery life cycles and potentially to transform markets in need of cost-effective energy storage. Based on these findings, the authors advise further investigation focused on forecasting long-term battery degradation and analyzing second-use applications in more detail.

2.5 INFLUENCE OF DRIVING CYCLE

Sukanya et al (2006) proposed a method to develop a driving cycle representing the Bangkok traffic. A method for selecting the representative road routes in Bangkok was firstly proposed. A gasoline passenger car equipped with a real time data logger was then used to collect speed-time data under
actual traffic along the selected road routes in Bangkok urban area for two months. The driving characteristics were analyzed from the speed-time data and its target driving parameters were defined and evaluated. The method for generating the driving cycle was then proposed and described. After achieving a driving cycle, exhaust emissions and fuel consumption of a vehicle were measured by driving a car on a standard chassis dynamometer according to the obtained Bangkok driving cycle. Comparison of the exhaust emission test and fuel consumption test results obtained from the constructed driving cycle with those obtained from the presently-adopted European standard cycle had been made.

Biona and Culaba (2006) demonstrated the process of the development of a dynamometer test cycle that would be reflective of the actual driving conditions in Metro Manila. The development of such test cycle would be vital to the development of emission factors. The study covers the gathering of actual speed time data, development of the instrumentation device for the said activity, analysis of the data gathered and extraction of a test cycle. Results were compared to the Indian drive cycle to demonstrate the inappropriateness of adapting drive cycles derived from other areas.

Gonder (2007) formulated an approach that employs route-based control could improve HEV efficiency at potentially minimal additional cost. He evaluated a range of route-based control approaches and identifies look-ahead strategies (using input from “on-the-fly” route predictions) as an area meriting further analysis. Given the increasing prevalence of GPS in vehicles, this advance has the potential to provide considerable aggregate fuel savings if applied across the entire national fleet. For instance, a 3% across-the-board reduction in HEV fuel use would save nearly 6.5 million gallons of fuel annually in the United States. These estimated savings will increase further as HEVs achieve greater market penetration.
Lukic et al (2007) tried to develop a driving cycle of the auto rickshaw in a typical large Indian city, in their case, Delhi. First, they considered the existing driving cycles used in India are considered as candidates. Since these data were not applicable, GPS data collected at various times of the day were applied to the analysis. They derived the new driving cycle from the gathered information via GPS data as well as surveys of auto rickshaw drivers in India, which helped to get the entire picture for the driving cycle.

Chris et al (2007) presents a comparison between two of the emerging technologies in automotive systems, hybrid drivetrains and telematics capability. Following the development of an optimal hybrid configuration that matches the performance of the baseline test vehicle, it was found through simulation that the fuel economy improvements possible through optimal hybridization ranged between 15% and 25% relative to the baseline vehicle over three standard urban drive cycles. The test vehicle was then equipped with telematic capability and an algorithm proposed that made use of preview information provided by the telematics to determining the vehicle’s modified speed at each point of the drive-cycle. Feed forward information about traffic flow supplied by telematics capability is then used to develop alternative driving cycles firstly under the assumption there are no constraints on the intelligent vehicle’s path, and then taking into account in the presence of ‘un-intelligent’ vehicles on the road. It is observed that with telematic capability, the fuel economy improvements equal that achievable with a hybrid configuration with as little as 7 s traffic look-ahead capability, and can be as great as 33% improvement relative to the un-intelligent baseline drivetrain. As a final investigation, the two technologies are combined and the potential for using feed forward information from a sensor network with a hybrid drivetrain is discussed.
Ayman et al (2009) demonstrated that, more than any other vehicle powertrain, PHEV benefits are dependent on the driving cycles from both an aggressiveness and distance point of view. Different powertrain configurations, including conventional, HEVs and several PHEVs have been simulated on more than 100 real world daily drive cycles. The simulation results demonstrated significant fuel economy gains both with HEVs and PHEVs with fuel displacement increasing linearly with available electrical energy. Since the drive cycles have different characteristics based on distance, the benefits of each vehicle configuration depend on how far the vehicle is driven. While the electrical consumption is similar for small and long driving distance, the main differences occur during medium trips. Based on the assumptions considered, the cost of PHEVs remains high. In addition, achieving the same payback period between two battery pack options requires longer driving distances for larger battery packs.

2.6 PERFORMANCE TESTING AND EMISSION ANALYSIS

In the present economic crises, many people want low powered small vehicles with fuel economy and the automakers are shifting their production to more fuel efficient and environmental friendly vehicles to satisfy customer demands. The automakers are working to promote hybrid vehicles because their fuel efficiency and low emissions make them the ideal solution to the current state of the world. Plug-in hybrids are making their way into the spotlight, making electric vehicles a serious possibility.

The Electric Power Research Institute and Daimler Chrysler have tested plug-in hybrid Sprinter vans with 20 to 30 miles of ZEV range (EPRI 2008). As per their research, compared to non plug-in hybrids, plug-in hybrids offer 35%–65% reduction in greenhouse gases and 40%–80% reduction in petroleum. General Motors Chevy Volt, a series hybrid, where only the
electric motor powers the wheels and the gasoline engine recharges the lithium-ion batteries (Fuel Cells Bulletin 2007). Ford with Airstream developed a concept car HySeries combines a lithium-ion battery pack with a compact fuel cell system which operates in steady state, resulting in reduction in size, weight, cost and complexity of a conventional fuel cell system by more than 50% (Austinenergy 2008). The California Cars Initiative has converted the Toyota Prius into Prius Plus. The Prius Plus achieves roughly double the gasoline mileage of a standard Prius and can make trips of up to 10 miles using only electric power. As per California Air Resources Board studies, the battery operated electric vehicles emit at least 67% lower greenhouse gases than petrol cars. Whereas PHEV with only a 20-mile all-electric range is 62% lower (Calcars 2009).

Argonne national laboratory, U.S.A., a transportation R&D estimated the impact of plug-in hybrid electric vehicles and analyzed typical travel behavior, new technology penetration patterns, and pathways for vehicle fuels. They analyzed on the Patterns of charging PHEV battery packs, petroleum usage reduction and well-to-wheel energy and greenhouse gas emissions. Combining PHEV simulation results with evaluation of travel behavior from a national survey, they developed a concept which eliminates vehicles that travel less than a PHEV’s electric range per day, since a PHEV is not cost effective for these customers. 20 miles is the most effective PHEV range for reducing oil usage.

In 1997, Honda Motors released a hybrid two-wheeler concept in the Tokyo motor show with the key goals of a 60% reduction in CO₂ emission and 2.5 times better fuel-efficiency. In this system, a water-cooled 49 cc gasoline engine packed with a DC brushless electric motor for driving the rear wheel. The gasoline engine delivers power for high-speed performance and for hill climbing while the electric motor is engaged for low-speed cruising.
Biona (2007) conducted an analysis to investigate the fuel use and emission reduction potential of incorporating hybrid systems to two stroke powered vehicles. Carbureted and direct injection two stroke engine hybrid systems were investigated and compared with the impact of shifting to four stroke engines. Results showed that hybridized two stroke powered systems would be able to provide far better environmental and fuel reduction benefits than the shift to new four stroke vehicles. He recommended that the development of such technology specifically for two stroke vehicles be seriously pursued.

Constantine and Kyle (2008) assessed the life cycle GHG emissions from PHEVs and found that they reduce GHG emissions by 32% compared to conventional vehicles, but have small reductions compared to traditional hybrids. When charging PHEVs with electricity that has a GHG intensity equal to or greater than our current system, their results indicate that PHEVs would considerably reduce gasoline consumption but only marginally reduce life cycle GHGs, when compared to gasoline–electric hybrids or other fuel-efficient engine technologies. With a low-carbon electricity system, however, plug-in hybrids could substantially reduce GHGs as well as oil dependence. The effect of PHEVs on GHG emissions from the transportation sector will depend on the rate of consumer adoption. Their focus on low, current, and high GHG-intensive electricity scenarios allows decision makers to think about what an electricity system should look like, over various adoption scenarios, if PHEVs are pursued as a source of large GHG emissions reductions. With the slow rate of capital turnover in the electricity sector, a low-carbon system may require many years to materialize. Considerable reductions in greenhouse gas emissions using plug-in hybrids in the coming decades will require decisions within the next ten years to develop a robust low-carbon electricity supply.
Ahmed (2009) developed a linear approximate emission model for transportation sector and a non-linear more accurate model for electric power sector for estimating the impact of one million EVs on emission reductions. Load leveling model and smart grid model are investigated. From the simulation results, emission reduction is not guaranteed in the load leveling model. On the other hand, significant amount of emission will be reduced if smart grid model is applied. However, it needs around $35 billion of investment on renewable sources. Future work will involve the use of more accurate emission model for the transportation sector and a load forecasting model with EVs using eco-traffic route data for accurate emission calculations.

Salil et al (2010) have developed motor vehicle projections (highway vehicles and two-wheelers), related oil demand, and carbon dioxide (CO₂) emissions for India until the year 2040 by analyzing historical vehicle stock and sales data for India, vehicle growth trends in developed and developing economies, trends in fuel mix of Indian vehicles, variation in vehicle use with increase in per capita GDP, policies of the Indian government on infrastructure development, growth in the number of personal vehicles, and regulation of the fuel economy of motor vehicles. In 2004, there were 47 two-wheelers per 1,000 people in India. For the past five years (2005–2009), 7.1 million two-wheelers have been sold annually, on average. They observed that, two-wheeler ownership is expected to decrease for upper- and middle-income classes, but increase for the lower-middle income class. The Indian two-wheeler population will exceed China’s two-wheeler population between 2010 and 2020, and it will have the largest two-wheeler stock in the world (between 301 and 359 million by 2040).
2.7 ECONOMIC ANALYSIS

Karl (2005) developed a methodological approach to combine a technology assessment of the major subsystems of a personal electric vehicle with a technical model of vehicle performance in order to estimate the cost and mass of a vehicle for a given set of functional requirements. Personal electric vehicles offer several potential benefits to consumers and to society including lower transportation costs, reduced trip times and lower environmental impact. Personal electric vehicles are technically feasible now. However, suppliers have not yet arrived at a set of practical vehicles that best match technical feasibility and consumer demand. Part of the challenge is to understand the relative trade-offs among cost, weight, range and other dimensions of vehicle performance. His article estimates the technological frontier defined by these trade-offs. This frontier illustrates what is likely to be technically possible. The question of what is commercially feasible remains. However this question will be answered by suppliers and consumers in the marketplace in the coming years.

Simpson (2006) presented a comparison of the costs and benefits of PHEVs relative to HEVs and CVs. Based on the study results, there was a very broad spectrum of HEV-PHEV designs with greatly varying costs and benefits. In particular, battery costs, fuel costs, vehicle performance and driving habits had a strong influence on the relative value of PHEVs. The author said that it was difficult to predict the future potential for PHEVs to penetrate the market and reduce the petroleum consumption. However, the potential for PHEVs to reduce petroleum consumption per-vehicle is clearly very high. However, it seems likely that the added battery capacity of a PHEV (four wheeler) will result in significant vehicle cost increments, even in the long term. However, the large petroleum reduction potential of PHEVs offers significant national benefits and provides strong justification for governmental support to accelerate the deployment of PHEV technology.
Jonathan et al (2008) examines the key forces driving and resisting strong market growth of E2W, what is causing these forces and how these forces are inter-related using FFA methodology. Through this analysis, we conclude improvement in E2Ws and battery technology is a driving force that can be partially attributed to the open-modular industry structure of suppliers and assemblers. This type of structure was made possible by the highly modular product architecture of E2Ws, which resulted in product standardization and enhanced competition amongst battery technologies. Growing air quality and traffic problems in cities in part due to rapid urbanization has led to strong political support for E2Ws at the local level in the form of motorcycle bans and loose enforcement of E2W standards. There are softer signs of national support for this mode in part due to national energy efficiency goals. Public transit systems in cities have become strained from the effects of urbanization and motorization, which has stimulated greater demand for "low-end" private transport.

Nan and Michael (2009) developed a database on all transport modes including passenger air and water and freight in order to facilitate the development of energy scenarios, and assess the significance of technology potential in a global climate change model. Transportation mobility in India has increased significantly in the past decades. This has contributed many energy and environmental issues, and an energy strategy that incorporates efficiency improvement and other measures needs to be designed. An extensive literature review and data collection has been done to establish the database with a breakdown of mobility, intensity, distance, and fuel mix of all transportation modes. Energy consumption was estimated and compared to aggregated transport consumption reported in IEA India transportation energy data. Different scenarios were estimated based on different assumptions of freight road mobility. Based on the bottom-up analysis, they estimated that the energy consumption from 1990 to 2000 increased at an annual growth rate
of 7% for the midrange road freight growth case and 12% for the high range road freight growth case corresponding to the scenarios in mobility, while the IEA data only show a 1.7% growth rate in those years. Ultimately, however, energy-related environmental impacts, particularly climate change, are a global issue. They hope that continuing research applying the approach presented above contributes to the understanding of global energy-related emissions and toward strategies of their reduction.

Valerie et al (2010) examined the commercial potential of PHEVs, their implications for electricity and petroleum use, and their potential contribution to reducing CO$_2$ emissions in the US and Japan. The results indicated that PHEV vehicle cost could be a significant barrier to market entry. PHEV costs of 15% above conventional vehicles are very favorable for adoption but markups above 80% are prohibitive unless there are no other low carbon transportation alternatives and there is a strong carbon constraint. Many PHEV cost estimates suggest a cost premium today of around 30–80% above conventional vehicles. Thus, a significant contribution from PHEVs would require advances in battery technology that reduce cost and increase range at the optimistic end of experts’ estimates. Another factor affecting the attractiveness of the vehicle is the all-electric range and how that influences the proportion of miles traveled only on electricity. Varying this proportion (essentially the all-electric range of the vehicle) had some effect on commercial viability but much less than the vehicle cost.

2.8 RELATED PATENTS

Fields and Metzner (1982) developed a car which has, in combination, a heat engine driving a set of front wheels, storage batteries and an electric motor driving a set of rear wheels. It also has a system for selecting electric or heat engine drive either manually or automatically and a single accelerator for
controlling either mode of drive. Battery charging power is derived from the electric motors acting as generators driven by the rear wheels while the vehicle is in heat engine drive and the battery charging rate is selected by the operator. Changeover from electric drive to heat engine drive is simplified by a changeover system and excessive loading of the heat engine by the battery charging system is eliminated on hills and during acceleration by a hill and acceleration sensing system. The car is designed for low speed and stop and go driving powered by the electric motors while the heat engine may be used for high speed and long distance travel.

Sakai et al (1998) developed a series hybrid vehicle comprises a generator driven by an internal combustion engine, a battery chargeable by generator, an electric motor rotated by electric power of generator and battery. A parallel hybrid vehicle comprises a battery chargeable by an electric motor and selectively uses an internal combustion engine and electric motor as driving source for driving vehicle wheels. In these hybrid vehicles, there is a sensor for detecting the state-of-charge (SOC) of battery. An output of generator or internal combustion engine is controlled based on each the SOC and a variation the SOC.

Tamai et al (2001) developed a fuel management control method for a hybrid electric vehicle drive having an internal combustion engine and an electric motor arranged in parallel such that both can propel the vehicle; the system including an electric motor driven fuel pump and a programmable microprocessor; and wherein the method further includes monitoring vehicle speed and sensing braking pressure and directing signals of both vehicle speed and braking to the microprocessor and processing such inputs in accordance with an aggressive fuel management program including shut-off of fuel flow to the gas engine in response to vehicle braking at vehicle speeds above a predetermined maximum hysteresis speed and maintaining the fuel shut-off during vehicle coasting above a predetermined speed while controlling the
electric motor to provide regenerative braking or vehicle start during such fuel shut-off modes of operation.

Tamai et al (2003) developed a propulsion system for use in a hybrid vehicle. The propulsion system includes an internal combustion engine, an electric motor/generator operatively coupled to the internal combustion engine, an electric storage medium and a propulsion system controller for actuating the propulsion system. The propulsion system controller varies the operating conditions of the electric motor/generator system in response to operating conditions of the vehicle. The propulsion system controller further varies the operating conditions of the electric motor/generator during an engine cranking sequence.

Sugiyama et al (2006) developed a hybrid drive unit for vehicles, in which a power distribution device is arranged in a power transmission route between an engine and a wheel, in which the power distribution device has a first to fourth rotary elements capable of rotating differentially with one another, in which a first motor generator is connected to the second rotary element and a wheel is connected to the fourth rotary element, and which is capable of steplessly controlling a speed change ratio of the first rotary element and the fourth rotary element of the power distribution device comprising: a second motor generator connected to the third rotary element of the power distribution device; a third motor generator connected to the wheel in a power transmittable manner; and an electric circuit for allowing exchange of electric power among individual motor generators.

Holz et al (2007) developed a method and a device for engine stop/engine start of hybrid vehicles, which includes an internal combustion engine and an electric machine which is coupled to the internal combustion engine and is selectively able to be operated regeneratively or motively, the engine speed can be detected and compared to a limit speed to initiate the
stopping of the engine in a hybrid vehicle using an automatic start/stop mechanism and if the engine speed drops to the threshold speed, the engine is stopped, the electric machine being switched over into the motive or the regenerative operation when the limit speed is reached; the electric machine assuming the limit speed, whereas the fuel supply of the internal combustion engine is shut down or remains shut down and the electric machine initiates the stopping of the internal combustion engine.

Ambrosio and Joseph (2009) developed a parallel hybrid vehicle system utilizing the power take off (PTO) connection on an automatic transmission as a transfer port for a secondary device is described for both driving modes and stationary operation. The secondary device is a battery powered electric motor providing motive power or regenerative braking in driving mode or providing power to accessories typically mounted to a conventional PTO while stationary.

Hafner and Schurr (2009) developed a vehicle comprises: a consumable fuel powered engine, a battery and an electric motor powered by the battery. The battery is rechargeable both from an external electric power source and from the consumable fuel powered engine. A computer receives data as inputs and providing outputs, wherein the input data includes an expected state of the electric power source at a time when the vehicle is expected to be coupled to the electric power source. The outputs include control signals to control the state-of-charge of the battery during the time the vehicle is expected to be coupled to the electric power source.

2.9 SUMMARY

In India, two-wheelers play a vital role in fulfilling personal transportation, especially in urban areas due to their maneuverability and affordability. They contribute to nearly two-third of the vehicle population in
India. The high fuel consumption and emission contribution of two-wheelers in urban areas needs to receive more attention in order to improve the near-term sustainability of energy and urban air quality in the future. Therefore, the implementation of plug-in hybrid technology for two-wheelers will result in reduction of greenhouse gas emission and petroleum oil independency to a large extent. The plug-in concept is implemented in certain concept cars and two-wheelers in the market in a limited way. Following are the important conclusions drawn from the above literature review:

- Modeling, simulation, sizing and selection of powertain components for the plug-in hybrid electric two-wheeler are based on all-electric range, driving style and battery type.

- There is a need for development of optimum control strategy for plug-in hybrid electric two-wheeler to manage the energy and power between hub motor with battery pack and IC engine.

- Estimation of correct battery type, battery energy capacity and its mass for different all-electric range may vary based on driving cycle.

- Economic and emission reduction analysis will help the commercialisation of plug-in hybrid electric two-wheelers.

The above factors from the literature survey clearly show the available scope for the present work. The objectives of the study and methodology adopted are presented in the next chapter.