CHAPTER 2

Review of Literature

The literature search was mainly focused on topics related to Electric and Hybrid cars. The review of publications and research work revealed the basic guidelines and area of work need to be conducted exhaustively on a particular model of car, where positive result is expected, in favor of society and future demand for saving of fossil fuel and environment pollution point of view.

This chapter of literature review is divided into seven sections:

2.1 Electric vehicles (EV)
2.2 Hybrid Electric Vehicles (HEV)
2.3 Fuel Cell Powered Hybrid Electric Vehicles (FCHEV)
2.4 Design Modeling, Simulation and Analysis software package development and utilization:
2.5 Batteries for EV and HEV
2.6 Controllers for EV and HEV
2.7 Regenerative braking and other technological gadgets for improvement in saving of Fuel consumption
2.8 Automotive Industry Standards (AIS) related to vehicles retro fitted with Hybrid Electric system.

The research papers available for viewing and reference on internet search engines and through related websites for the knowledge and information sharing on public domain is cited below.

The literature search was mainly focused on topics related to Electric Vehicles (EV), Hybrid Electric Vehicles (HEV) and Fuel Cell Powered Hybrid Electric Vehicles (FCHEV). The publications related to simulation, critical analysis and empirical study using available software were reviewed in detail. Also, study of vehicular propulsion
systems based on alternate sources of energy was attempted to a certain extent; however it was restricted more importantly to the literature related to fuel saving objectives, rather than research work carried out for reduction in constituents of harmful pollutant exhaust gas emission perspective and saving of environment against global warming.

Since, the objective of the proposed work is to save fuel consumption on existing cars, which will automatically have crucial impact on the automotive emission; the main attention was paid to review of literature on the work carried out in the past by learned researchers in the field of fuel saving.

The literature of prime importance to be mentioned here (in reference to the work carried out by me), under main classifications and sub classifications is as follows:

2.1 Electric vehicles (EV):

Morkel, (2010) [20] in this paper the requirement for infrastructure development, challenges and opportunities for design and deployment of emerging infrastructure, related to Plug in Electric Vehicle (PEV) and the potential benefits are summarized in detail. The author had addressed the crucial points to maximize the benefits from the opportunity for reducing fuel consumption, from battery manufacturing to communication and control between the vehicle and the electric power grid to provide for clean electricity with safety.

Holms et al, (2010) [21] explained in their report the working of electric vehicle and compared it with the conventional internal combustion engine and hybrid electric vehicle. The report provided the details of advantages and disadvantages of Electric Vehicles along with the future views of technology.

Eberhard et al, (2006) [45] in their paper on “The 21st Century Electric Car”, had experimented Tesla Roadster EV with lithium ion batteries, for well – to – wheel energy efficiency and well – to – wheel level of emission. When compared with Natural gas engine, hydrogen fuel cell, diesel engine, gasoline engine and hybrid gas/electric car, well – to – wheel energy efficiency found to be high and well – to – wheel emission found very low for Tesla Roadster EV.
Santos et al, (2006) [44] studied the power converter and its control for an electric traction vehicle and solutions encountered during development were discussed in this paper. The focus was directed towards strategies and construction problems for the power converter (controllers), the protection and control of the power train. The vehicle considered for the study used 11 KW – 48 V DC motors. The safety concerns were important to be considered for the proposed architecture, because this motors needed a high current value of 200 A (approximately). A DC-DC power converter was discussed in detail to achieve energy conservation and low power dissipation depending upon the motor operation demands, in forward and reverse direction movement of the vehicle. The paper stated the reasons for need / importance for control of variable output current of the converter rather than voltage control under intuitive correlation between throttle control and torque developed w.r.t. ICE as well as for the protection and safety of Motor, controller and several electrical & mechanical components. The methods of current control, in-particular sliding mode control were discussed.

Chetan Kumaar Maini, (2005) [46] in his paper indicated potential requirement of the design and development of globally competitive small electric concept vehicle for India and concluded that EVs are the best solution to reduce pollution in cities, and important societal and economic benefits would result by implementation of EVs and HEVs. The paper also outlined the role played by the Government and communities worldwide to promote and accelerate EV program.

2.2 Hybrid Electric Vehicles (HEV):

Debabrata Das, (2011) [74] in this paper of International Journal of Electric and Hybrid Vehicles; he had articulated details of demand for hybrid cars in India.

Johann et al, (2010) [18] proposed electrification of rear axle with view to derive over all energy efficiency of the entire vehicle and meeting the customers’
expectations. The paper focused on the hybrid power train concept with an ICE in the front and two in wheel motors at the rear drive shaft. The paper gave an impact on different design characteristics of investigated electric motors types. The paper also focused on the operational advantages and disadvantages of different electric motor types on their potential for rear axle powering units. The study indicated fuel saving that can be expected by proposed method of hybridization.

**Marinescu et al, (2010)** [19] FISITA F 2010 A-089 presented aspects regarding a diesel electric hybrid concept car. The diesel power train was mounted in front side, in transversally classic position and the electric power train was mounted in the rear side. The performance tests on the prototype vehicle with electric power train and the diesel power train as 4 wheel drive concept, were yet to be carried out in laboratory.

**Kessels et al, (2010)** [75] FISITA SF 2010 A-096, Discussed the proposed model based integrated power train control for energy management & emission management for reduction of hazardous tail pipe emissions for hybrid electric vehicles as well as the reduction in operational cost of the vehicles was importantly considered, in this paper. The case study was presented for a heavy duty hybrid electric vehicles with SCR - deNOₓ. It was indicted that till the time temperature of after treatment system is low, proposed control system focuses on emission management and subsequently on when the after treatment system is sufficiently hot, energy management would take over the control. The results demonstrated the trade – off between operational cost and emission, derived from the proposed integrated power train control.

**Carlson et al, (2008)** [36] had evaluated the distinction in fuel average of two models of hybrid electric vehicles over wide range of ambient temperatures (–14° C to 31° C) on predefined urban driving route, for study of dependence on ambient temperature. Given the fuel economy offered by HEV, over the conventional vehicle technology, the variation of performance was investigated for cold and hot temperature effect on HEV operational efficiency, for an on road
predefined urban driving route. The results showed that the battery power control limits and engine operation changed dramatically with temperature.

Chau et al, (2002) [51] dealt with various situations of vehicle with the objectives of deriving maximum fuel economy, minimum emissions, minimum system cost and good driving performance in this paper. The emphasis is laid on power management strategy of drive train. The power flow control for various HEVs was also elaborated.

Chau et al, (2001) [52] proposed an energy management system for hybridization and coordination of multiple energy sources. It is presented that unique advantage of various EV energy sources can be fully utilized, leading to optimum fuel economy. Two parameters are mainly concentrated for measurements viz. mass ratio and hybridization ratio in correlation with driving cycle.

Plotkin et al, (2001) [55] has assessed in his paper the Methodology, Analytical issues and interim results: in terms of energy impact and costs of hybrid electric vehicles, the research was work carried out for DOE (under Argonne National Laboratory for Transportation Technology R & D Center). He indicated that the research work on hybrid electric vehicle, if made successful, would drop cost to an attractive level of net cost basis.

2.3 Fuel Cell Powered Hybrid Electric Vehicle (FCHEV):

Uzunoglu et al, (2007) [40] in his paper focused on the design and modeling of Fuel Cell/ Ultra Capacitor (FC/UC) based Hybrid vehicular power system as well as the development of power flow control strategies, using the simulation model. FC provides power for base load and UC supplied additional power during peak power demand or load switching. The large, very complex and expensive FC technology systems were studied to improve system efficiency, for vehicular application by utilizing proton exchange membrane fuel cell (PEMFC) in order to develop fairly accurate model to overcome difficulties associated with FC. An attempt had been made to develop a model / feasible option to provide
for power during transient operating conditions such as start up, sudden changes in load, and acceleration.

Ahluwalia et al, (2005) [48] stated that the standard US drive cycles used for measurement of fuel economy operates on 20% of rated power of the engine. He said that the Fuel Cells are more efficient at part load than rated load. The author has studied to assess the potential for improvement in fuel economy of a FCEV by hybridization on a sedan vehicle, with direct hydrogen pressurized FC system as energy converter and an energy storage system (ESS) of Lithium – ion battery pack, on different drive cycles as function of degree of hybridization (DOH).

The study had been carried out by holding the combined rated power of the FC system and ESS as constant. Consequently, the FC system was down sized as the degree of hybridization (DOH) is increased by making the ESS larger. The fuel economy of hydrogen fuel cell vehicle was found, on the basis of miles per gallon gasoline equivalent (mpgge).

Ogburn et al, (2000) [59] described design and construction of a fuel cell hybrid electric vehicle conversion. A model was developed by using advisor for small fuel cell stack and validation of model was done with Virginia Tech – FCHEV on EPA (US Environment Protection Agency) city and highway driving cycles. Comparison of model v/s test data of total fuel cell system energy production, total energy usage from the vehicle energy storage system and total vehicle electrical energy use concur within 10%, overall vehicle fuel economy accuracy was found to be within 1% on city driving cycle and within 6% on highway.

2.4 Design Modeling, Simulation and Analysis software package development and utilization:

Markel et al, (2002) [49] wrote an overview of Advanced Vehicle simulator (ADVISOR), developed by National Renewable Energy Laboratory, US Department of Energy. Advisor based on MATLAB/Simulink and flexible yet robust analysis for advanced vehicle modeling, was primarily used to quantify
fuel economy, the performance, and the emissions of the vehicles that use alternative Technologies.

ADVISOR was created in MATLAB/Simulink environment. MATLAB provides easy to use programming environment for performing calculations while Simulink and be used to represent complex systems graphically using block diagrams. The model did not consider, driver interface, road condition and traffic condition inputs, however several no. of drive cycles are from the available data base can be used to assess the performance parameters, at base level. Many possible scenarios can be evaluated quickly. The results can be utilized to improve the performance of a new vehicle design. ADVISOR ws used to quantify the fuel economy, performance and emissions of vehicle that use alternative technologies.

Assanis et al, (2001) [56] described the methodology for integrating vehicle and engine simulations in this article. The feed-forward model of the engine simulation was modified to allow its linking with the vehicle model, and an engine component scaling routine was added to facilitate system sizing studies. A design optimization frame work was then used to find the best overall engine size, battery pack, and motor combination for minimum fuel consumption within proposed performance criteria. The researchers had completely omitted emission models.

Hofmman et al, (2004) [76] indicated the influence of design specifications for secondary power source (with the understanding of motors considered as secondary power source) can enhance the fuel economy, emissions, comfort, driveability and safety, the paper discusses the influence of the generic design specifications for motors (i.e. power ratings, storage capacity and energy conversion efficiency) including efficiency of brake energy recovery. This paper relates to the problem statement for determining an optimal hybrid drive train topology and component technology aiming at a certain driving function improvement and causes for difference in realized output driving functions (its relations with respect to drive train topology, the technology or the control). The paper also focuses on the sensitivity analysis of design input variables. They
concluded that fuel saving increases significantly with increase in power rating, accumulator size and energy conversion efficiency of secondary power source.

**Mierlo et al., (2001) [54]** developed an interactive, user friendly vehicle simulation program allowing simulation of electric as well as ICE to study power flows in drive train and corresponding component losses as well as to compare different drive train topologies. The comparison indicated the level of performance in terms of consumption of fuel as well as electricity and reduction in harmful exhaust emission gases.

The general objective of development of this program was to know the energy consumption of a vehicle while driving on certain reference cycle. The program runs on LabVIEW environment. For electric vehicle (EV) it indicates current drawn from battery, for ICE energy consumed is in terms of fuel and Hybrid vehicles it corresponds to consumption of Fuel together with energy drawn from Battery. A good correlation between measurements and simulation results was found.

**Wipke et al, (1999) [61]** had discussed the new features and capabilities of second generation advanced vehicle simulator ADVISOR 2.0 released by NREL.

ADVISOR has been applied to many different system analysis problems, such as helping to develop SAE J1711 test procedure for hybrid vehicles and helping to evaluate new technology as part of Partnership for a New Generation Vehicles (PNGV) technology selection process.

**Butler, (1999) [62]** discussed in this paper a simulation and modeling package (V – Elph 2.01), for in depth studies of electric vehicle (EV) and Hybrid EV (HEV) configuration as well as energy management strategies by creating components as sub systems that can be used interchangeably. The major components includes: electric motors, internal combustion engines, batteries and support components to model and simulate drive trains having pure electric,
series hybrid and parallel hybrid configurations for analysis of energy efficiency, fuel economy and vehicular exhaust emissions.

Rahman et al, (1999) [60] depicted the design methodology for heavy duty transit bus, considering performance specifications, motor size estimation, battery size estimation, and determination of gear ratios, acceleration performance and estimation of auxiliary power unit (combination of ICE-generator for series hybrid vehicle). He concluded that the V-ELPH 2.01 can be useful and it provides valuable assistance to HEV designers and understanding to researchers in the area of hybrid vehicles.

Cuddy et al, (1997) [65] at SAE International Congress & Exposition, Detroit (Feb 24-27/ 1997) 970289, evaluated Parallel and Series hybrid vehicle configurations for feasibility, using NREL’s flexible software package ADVISOR in this paper. Analysis of fuel economies of the two diesel vehicles (Parallel and Series hybrid) were compared with diesel powered ICE vehicles of comparable technology. The paper concluded that a parallel hybrid achieved fuel economy 24% better than ICEV while series hybrid improves by 18%. The author stated that the sensitivity of the fuel economy was strongly related to the various vehicle and component specification differences and parameters that determine the impact was important to note.

2.5 Batteries for EV & HEV:

Pesaran et al (2009) [25] projected that Plug –In Hybrid Electric Vehicles (PHEV) had potential over conventional vehicles in next ten to twenty years. However, he claimed that main barriers for the commercialization of PHEVs were the cost, safety, and life of batteries. This paper analysed the process for defining vehicle platforms, vehicles performance target, the desired equivalent electric range operating strategy, and the state of charge. The paper presented assumptions, analysis, discussions, and the resulting requirements adapted by U.S. Advanced Battery Consortium (USABC).
Pesaran et al, (2009) [26] has discussed about mechanical, electrical, and thermal integration issues and vehicle interface issues that could impact the cost, safety, and life issues of batteries for plug-in and hybrid electric vehicles in this paper. Impacts of different type of cells were compared for establishing the advantages and disadvantages. In spite of significant efforts to address the issues, the best of the cells may not perform as expected, because of the operational environment, when integrated into packs for vehicular application. The author concluded that the smaller capacity cells though easy to pack, but developed higher no. of interconnections of failures.

Burke, (2007) [39] explained the application of batteries and ultra capacitors in electric energy storage units for electric vehicles and charge sustaining, plug – in hybrid electric vehicles in details, in this paper. The study was focused on lithium-ion batteries and carbon/carbon ultra capacitors. The energy density and power density characteristics of battery and ultra capacitor technologies are discussed. From the comparison of simulation results for energy consumption, fuel economy and grid electricity usage on federal and highway driving cycles, it was concluded that EV with lithium ion batteries could be designed for 240 km range, with acceleration comparable to conventional ICE vehicle.

Duvall, (2005) [47] in his paper outlined the development of battery test evaluation regime for plug in hybrid electric vehicle in particular. It described an ongoing process for life cycle performance validation for the duty cycle a plug in hybrid electric vehicle was subjected to.

Stuart et al, (2002) [66] had developed a modular battery management system, for active equalization of voltage and temperature different cells. Because, an active battery management system was considered must for monitoring, control and balancing of the entire set of battery pack. Proper electric and thermal management of HEV batteries was taken as very important, because during operation – voltage and temperature difference in different cells could lead to electrical imbalance and decrease performance. The results of testing showed that weight and volume of the modular battery management system were 70 % & 87 % less than the central system, respectively.
Yang et al, (2002) [50] considered the challenge for enhancement of limitation of travel range of electric Vehicles. The authors had attempted and compared the Al/air EVs life-cycle analysis with Lead Acid Battery operated EV as well Nickle Metal Hydride (NiMH) battery operated EVs. The author’s analysis claimed that (due to high energy density) only Al/air EVs are most capable, with respect to ICE and EVs, in terms of travel range, price and life-cycle cost.

Rebecca et al, (1999) [63] introduced rechargeable batteries characteristics and use, a module focusing on nickel – cadmium batteries, since batteries represent a large volume of toxic and hazardous material and these materials must be managed to avoid or minimize dissipation into the environment. To determine total environmental impact of a battery system, all stages of battery life were considered in this module for life cycle emissions and energy use estimated for NiCd batteries. Current battery collection and recycling practices were briefly explained and an expression for estimating NiCd recycling rate was given. The results stated were included for implementation programs by battery organizations, to improve NiCd battery collection and increased consumer education.

Johnson et al, (1998) [64] described the physical design, rate, cycle – lifetime, and self discharge performance of battery cells from various battery manufacturers, in this paper. The specifications and performance as well as design differences are discussed. The results showed that larger capacity gains are possible by using high capacity carbon electrodes. Different cells had shown different strengths and rapid discharge, cycle-life characteristics, depending upon use of hard carbons.

2.6. Controllers for EV & HEV:

Rahman et al, (2000) [57] made comparative study of Two HEV control concepts (Thermostat & Power split). Three Parallel HEV Architectures: Pre transmission, post transmission & continuously variable transmission hybrid were compared in this paper. The study included the effect of hybridization
factor and the ratio of electric power to total power. The paper very well defined optimum range of hybridization for the control concepts.

To minimize fuel consumption and emissions, importance of selecting appropriate HEV technology as well as to develop power flow control algorithm, was indicated.

The author had discussed various power control strategies: Thermostat, On/Off, power split. The paper concludes as per the simulation results showed a maximum of 1.4 times increase in fuel economy due to parallel hybridization over conventional car. The authors commented that increase in hybridization would decrease the engine size. Further, smaller more efficient engines would increase system efficiency to improve fuel economy further.

2.7. Regenerative braking and other technological gadgets for improvement in saving of Fuel consumption:

Castro *et al*, (2012) [7] studied the constraints arising out of motor installation in a confined space, based on in-wheel motors, increased un-sprung mass and integration of electric motor with friction brake. To address the slip regulation problem they had proposed tyre slip controller, wheel torque allocator and braking supervisor. The simulation results showed effectiveness of approach when compared with ‘Car Sim’ vehicle modeling software results.

Huang *et al*, (2012) [9] presented a nonlinear model predictive controller for regenerative braking control of light weight EV, equipped with in-wheel motors, for improving regenerative braking energy recovery. Simulation results based on a vehicle model in ‘Car Sim’ showed that the nonlinear model predictive controller is capable of restoring considerably more energy than conventional proportional – integral controller.

Panagiotidis *et al*, (2000) [58] carried out study on physics based REGEN simulation for diesel assisted HEV and taking advantage of graphical, symbolic
simulation tools. A model was developed capable of dealing with REGEN issues every time braking occurs, while in normal driving, emergency braking or driving in reverse mode as well as ABS operating conditions (i.e. avoiding wheels lock up) in all the three case as mentioned above. The model was aimed at helping the HEV designers to realistically predict fuel economy and emission improvements by computing the line and pad pressure for front and rear brakes. The amount of REGEN depended on the state of deceleration (i.e. brake pedal position) and wheel lock up avoidance algorithm.

It is indicated that depending on the HEV configuration, vehicle fuel economy can be enhanced through the incorporation of regenerative braking, storage and relative capability of energy that would normally be wasted as heat during braking by Mechanical, hydro-mechanical, or electromagnetic methods of regenerative braking system.

Dixon et al, [67] proposed a system using IGBT buck boost converter connected to the bank of ultra capacitors at the boost side and to the main batteries at the buck side, to allow higher acceleration and decelerations of vehicle with minimal loss of energy and degradation of battery. The simulation results showed that the control system could work properly, taking in to account battery voltage, state of charge, instantaneous current, the car speed, higher acceleration and deceleration with minimal losses of energy and degradation of main battery.

The classifications given above are indicative; and publications are listed under the related classifications, unless otherwise it specifically falls under the classification 2.7 as above.

The review of publications and research work revealed that exhaustive research work need to be conducted with concentrated effort on innovative technology, along with the prototype built for the experiments, where the basic guidelines and positive result is expected / available in favor of society and demand for saving of fossil fuel environment pollution, by reduction in consumption of fuel.
From the above cited references it is indicative that no work has been carried out for existing vehicles, in the direction of fuel saving through hybrid conversion and achieving implied reduction in exhaust gas emission. Hence, it is concluded that there is a need to develop fuel efficient car preferably by using permanent magnet brushless DC hub motors fitted directly in the rear hub on front engine front wheel drive vehicles with semi trailing link suspension. In the next few chapters attempt made by the author on development of methodology for conversion of existing 1400 CC diesel car in to HEV, has been discussed in detail.
2.8 Automotive Industry Standards (AIS) related to vehicles retrofitted with Hybrid Electric system.

AIS - 038: Constructional and functional safety. This standard deals with Battery operated vehicles related to requirements for construction and functional safety. Ventilation of battery to be provided for hazardous gases. Battery and power train protection by fuse or circuit breaker specification as per (AIS 007) mounting of batteries: no spillage of electrolyte

AIS - 039: Electrical energy consumption

AIS - 040: Range

AIS - 041: Net power

AIS - 049: Type Approval-Electrical vehicle

AIS - 102: Type Approval – Hybrid electrical vehicle

AIS - 123: Testing of retrofitted hybrid electric vehicle: permissible weight increase of 21 % {200 kg increase in weight for 1050kg un-laden weight of prototype vehicle (i.e. 19 %) is well within the specified limit}

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