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A Comparative Study of Hybrid Electric Vehicles

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Abstract: **-- Two big problems which restrict the development of automobile industry are environmental pollution and energy storage. With this concern, the Hybrid electrical vehicle has been developed to achieve energy saving and emission reduction. A conventional vehicle actuated with only internal combustion engine cannot enhance the fuel economy due to wide range operation requirement of the power train. Instead of this, a Hybrid electrical vehicle which uses ICE and two motors can effectively improve the efficiency of the power train. This type of Hybrid electrical vehicle provides four modes of operation, including Electrical vehicle (EV) mode, range extending (RE) mode, hybrid mode, and engine mode. Despite continuous development in HEV's: short range, long recharging time and cost still act as barriers to their widespread adoption. Therefore, the increasing interest in the development of HEV's has broken in new designs of HEV's namely Series Hybrid electrical vehicle, Parallel Hybrid electrical vehicle, Battery electrical vehicle, Plug-in Hybrid electrical vehicle, Range extending Hybrid electrical vehicle. This paper reviews technology used in HEV's, their types, the effect of different technology mixes for efficient battery recharging and their development towards sustainable, efficient and environmentally friendly transportation.**

***Keywords* — Series Hybrid electrical vehicle, Parallel Hybrid electrical vehicle, Battery electrical vehicle, Plug-in Hybrid electrical vehicle, Range extending Hybrid electrical vehicle.**

I. INTRODUCTION

A Hybrid electrical vehicle is a type of hybrid vehicle and electrical vehicle that combines a conventional internal combustion engine (ICE) system with an electric propulsion system. Electrification of power train is intended to achieve better fuel economy and better performance. Since from the time automobile industry was established , the concept of Electric vehicles is used .Until 1910, the Electric vehicle were more used than vehicles using ICE [1]. Increasing concern about greenhouses gases, has led further development of electrical vehicles. In this framework, power train electrification is a valuable solution because Electric vehicles do not generate pollutants. In additional to that, Hybrid Electrical vehicle has a degree of freedom that is obtained due to presence of an additional energy reservoir besides the fuel tank, that is, electric battery [2]. This means that, at any moment, either one of the sources, or by combination of the two can provide power to vehicle. In spite of, such large developments, HEV'S have some shortcomings, that is, short range, long recharging time. Consequently, the developing interest, has led to exploration of plug-in Hybrid Electrical Vehicle (PHEVs). The PHEVs offers the drivers the same range as ICE and in additional to that lead to environmental benefits, therefore PHEVs act as a range extending hybrid electrical vehicle. For a longer cruise mileage, a range extender (also called as Auxiliary power unit) is used in range-extending HEVs, along with that battery in RHEV can be charged from the external power grid [3].

II. STATE OF ART

The simplest definition for a Hybrid Electric vehicle is one that relies on two different power sources. Hybrids can basically be divided into three main types: full-hybrids, mild hybrids, plug-in hybrids. These are further sub divided as "muscle hybrids" and "micro hybrids".

A. Full Hybrid

Among the regular hybrids-not including the plug-in variety, full hybrids is the most fuel efficient. A full hybrid electric vehicle has an advantage of running on just the engine, just the battery, or a combination of both. A large, high capacity battery pack is needed for a full hybrid electric vehicle running only on battery.

The standard examples of full hybrid electrical vehicle are Toyota prius, Ford fusion Hybrids, Accord Hybrid by Honda's. Full hybrid electric vehicles can automatically choose to operate in series mode, parallel mode, or all electric modes [4]. These three modes are explained below:

1. Series Hybrid System

In series hybrid system, the combustion engine doesn't directly drive the wheels. The wheels are only powered by electric motor. Here the combustion engine drives an electric generator. The generator charges both the battery and powers an electric motor that moves the vehicle. In case of large requirement of power, the motor draws electricity from both the batteries and generator.

2. Parallel Hybrid

In parallel hybrid system, both an ICE and an electric motor are connected in parallel to a mechanical transmission. There are many advantages of parallel hybrid vehicles: There efficiency is higher during cruising and long-distance highway driving and have large flexibility to switch between electric and ICE Power compared to series hybrids.

3. Combined Hybrid

Combined hybrid systems have features of both series and parallel hybrids. There is a double connection between the engine and the drive axle: mechanical and electrical. The mechanical and electrical power paths are interconnected by split power path. The main principle behind the combined system is the decoupling of the power supplied by the engine from the power demand by the driver.

B. Medium Hybrid

In medium hybrid system, the amount of electric power needed is smaller than that of full hybrid, thus the size of battery is reduced. The electric motor, is mounted between the engine and transmission and acts as a large starter motor.

This electric motor operates both when the engine needs to be turned over, but also when the driver steps on the gas and requires extra power.

C. Mild/Micro Hybrid

Mild hybrids are type of conventional vehicles with oversized starter motors, which allow the engine to be turned off whenever the car is coasting, braking, or stopped. In mild hybrid, there is no motor-assist and no EV mode at all [4]. Therefore, few people consider them as hybrids.

D. Plug-In Hybrid

Plug-in hybrid vehicle is an essential gauge to achieve energy saying and emission reduction. The increasing interest in combining the desirable features of Electric vehicles with the range capability of conventional vehicle, has led to the investigation of plug-in hybrid electric vehicles which can offer drivers the same range as conventional internal combustion engine but can also lead to environmental benefits. Plug-in hybrid electric vehicle is a hybrid car with an added high capacity battery.

III. LITERATURE OVERVIEW

Ming et.al [5] developed new energy management strategy of plug in hybrid electric vehicle. The most important part in the research of PHEV, which has important influence on the performance of the whole vehicle, is the Energy management strategy. There are three main categories of energy management strategy. (a) rule-based algorithm [6]-[7]: this method gives an idea to limit the working range of parameters. This method has a simple structure, small amount of computation and high execution efficiency but it cannot guarantee the optimization of the vehicle fuel economy. (b) Intelligent control method: this method incorporate the human knowledge into the control system, e.g. fuzzy control [8] and neural network control [9] to solve many complex uncertain control problems. (c) Optimization algorithm: Here optimized math models are developed based on optimization theory by restriction of emissions, fuel economy. Presently used optimization methods are: swarm optimization [10], genetic algorithm [11] and dynamic programming algorithm [12]. After simulating and developing models for the three control strategies, the result shows fuzzy control strategy not only improve the fuel economy but also achieve more smooth control effect to alleviate the decline rate of SOC effectively than the other two energy management strategies.

Negarestani et.al [13] developed fast charging for plug-in hybrid electric vehicle. To fully charge a PHEV in a short period of time, fast charging station is absolutely necessary. In conventional HEVs, internal combustion engine is used to charge the vehicle's battery. But in plug-in hybrid electric vehicle, the battery can be recharged through electrical connections [14].There is a growing demand for PHEVs, so it is necessary to establish a proper charging infrastructure to meet their electrical energy demand. In this paper, a universal optimization problem has been defined, which minimizes the load variance while preserving battery health, while seeking to coordinate charging/discharging of PEV. At the same time, it's also important to design appropriate charging station, which is able to meet the expected demand [15]. An appropriate charging station should not only meet the charging demand at any time of the day, it should minimize the station operating cost as well. To meet the charging demand, electrical storage systems (ESS) can be used. The author here attempted to determine the optimal ESS size for fast charging stations considering the technological constraints.

ESS is also used to store electrical energy during off-peak hours and return the stored energy during peak hours. From this paper, we can wind up that the storage system application in a charging station can not only reduce the station costs, but also restrict network peak load increment. In addition, the studies show that by incorporating time- varying prices of electricity, installing storage system in the charging station are beneficial than incorporating fixed-rate price.

Yu et.al [16] presented a battery management system using non-linear model predictive control of Hybrid electric vehicle. The key technology of HEV is energy management. To investigate the energy management problem of a power-split HEV a model predictive control was used [17]. New charge/discharge control system supported by car navigation information was also developed for HEVs [18]. For energy management, dynamic programming was developed with equivalent consumption minimization strategy of a power HEVs [19]. None of the above explored a relationship between the battery power and future load for energy management. So in this paper, we apply the non-linear model predictive control to the HEV energy management system. The battery state of charge (SOC) is considered the only state of system and battery power as the only control input of the system. Here, a apparent relationship is explored between the battery power and the future road load for significant improvement in fuel economy.

Panday and Bansal [20] checked the performance of Hybrid electric vehicle under various temperature conditions. It is observed that the performance of vehicle varies with temperature and at higher temperature fuel economies are found to be better compared to lower temperature. On the other side, it is also observed that usage of battery at high temperatures for longer time reduces its life and performance. Battery plays an important role in HEVs and its performance is analyzed by different parameters like resistance, capacity, SOC. These parameters get influenced by the temperature, aging, and charging/discharging cycles. This paper is mainly concerned on the effects of temperature on battery functioning and impinge effect on vehicle performance. At high temperature, less activating energy is required for the chemical reaction to take place whereas at low temperature high activation energy is required for the chemical reaction to occur. Temperature variation affects the current, voltage and SOC of the battery which in turn affects the engine transition (on/off). The operating range of the vehicle is restricted by analyzing the effect of temperature to achieve the fuel efficient performance along with the longer life. At higher temperature fuel economies are high and at lower temperature fuel economies are lower, this verifies the theory of temperature effect on rate of reaction of battery cell.

Guan and Chen [21] developed adaptive power management strategy for a Four-mode Hybrid electric vehicle. The Four mode HEV consists of an internal combustion engine and two motors. Electric vehicle (EV) mode, range extended (RE) mode, hybrid mode, and engine mode are the four modes of operation of HEV. For maintaining the state of charge for charge sustaining adaptive PMS is designed. For adjusting equivalence factor of electric energy consumption based on SOC deviation and the change of SOC deviation, self-organizing fuzzy controller is employed. Adaptive PMS can effectively improve the fuel economy for different driving cycles. PMS can be classified into three types. The first type is rule based control [22] which is designed based on rules extracted from engineer expertise. The second type is the equivalent fuel consumption minimization strategy [23] which uses static optimization to achieve minimization of an instantaneous cost function. The third type is the global minimization [24] based on dynamic programming. Sun C et.al [25] used an adaptive–ECMS combined with a velocity Model predictive control for temporary driving information for real-time adaptation of equivalence factor (EF). Yan F et.al [26] employed Model predictive control (MPC) to design power management strategy (PMS). Borhan H et al. [27] devised a nonlinear and constrained optimal problem for the PMS design. After simulation of these methods, we find out that in RE mode, both ICE and integrated starter generator (ISG) operating points are operated around the optimal operating curve and for Hybrid and ICE modes, the ICE operating points fall in the low fuel consumption regions. Traction motor (TM) operates below middle velocity for the EV and RE modes. Traction motor provides additional power for the HEV mode when necessary. By using adaptive power management strategy, instantaneous cost function of the fuel consumption of ICE and the equivalent fuel consumption of the battery is minimized to obtain the optimum power distribution of ICE, ISG, and TM. After simulation of the models, results show that adaptive PMS has superior fuel economy improvement than ECMS for different driving cycles.

Martinez et al. [28] presented a paper on energy management in plug- in Hybrid electric vehicles. PHEVs are a solution for emission reduction and fuel displacement. A PHEV can be directly charged from a grid and have more degree of freedom to supply power demand than conventional vehicles. To maximize the overall power train efficiency and to minimize fuel consumption energy management is employed [29]. After measuring, PHEV impacts with an energy-based analysis, it is found that fuel consumption can be reduced through the electrification potential factor (EPF) [30].This paper highlights advantages and disadvantages of all existing approaches for energy management. It doesn’t conclude with a single algorithm preferred for PHEVs energy management, but support use of more than one algorithm to compensate for each other deficiencies.

Razi et al. [31] presented a new battery charger for plug-in HEV using Back to Back converter in a utility connected Micro grid. High volume, weight, low pressure, long charging time, deleterious harmonic effect, low reliability and flexibility are the drawback that most of battery chargers for PHEV have. The proposed structure in the work can run in four different modes: battery charging mode from grid (G2V) or micro-grid (M2V), vehicle to grid mode (V2G), and vehicle to micro-grid mode (V2H). Bi-directional battery chargers are used to operate PHEV as a distributed generation (DG) to supply power to the grid or micro-grids [32]-[33]-[34]-[35], this result to increase in flexibility and reliability but the other major drawbacks remain the same. In this paper, integration of PHEV with a main grid or micro grid is implemented by using back-to-back converter in a utility connected micro- grid. This structure involves: an AC micro-grid, in which load is fed from DG source, a battery charger, in which bidirectional DC/DC converter is used, and main grid. Power flow control between utility and micro-grid can be achieved by using back-to-back converters [36], which facilitate desired real and reactive power flow between the utility and micro-grid. The proposed scheme is very flexible and reliable and its excellent performance has been confirmed through extensive simulation on MATLAB/SIMULINK for various operating conditions.

Xiong and Yu [37] researched on Robust control for longitudinal impact of 4 wheel-drive HEV.A 4WD- HEV whose front wheels are driven by engine and rear wheels driven by in-wheel-motor, the engines intervention in driving will cause the longitudinal impact and influence the driving comfort. Disturbance rejection which is directly proportional to robust controller can effectively control the longitudinal jerk. Drive motor is able to reduce longitudinal impact caused by hybrid vehicle during the transmission shifting or the transition condition, because DM has advantage of torque control and rapid response. In this paper, rear motor is used to achieve vehicle longitudinal impact control.

Mineeshma et al. [38] used backward modeling approach for component sizing of EV/HEV subsystems. EV and HEV are developing rapidly being environmental friendly. For practical solution in terms of performance and size of power train components a number of electro mechanical systems and an optimal subsystem design is inevitable to arrive at a practical solution. To achieve the performance requirements with the optimum resources and to prevent unwanted wastage of natural resources at the same time, component sizing is necessary. Component sizing is estimated by equation based calculators by considering only one operational point. The optimal subsystem design of EV/HEV configuration can be achieved by using backward simulation. The performance of each component subsystem is decided by desired vehicle speed profile and vehicle dynamics.

Marignetti et al. [39] designed test equipment for HEV drive trains. With the growing demand in production of electric and hybrid vehicle, testing electric trains for performance assessment has become a key factor in the automobile industry. Drive train on the real vehicle can alternatively be installed by the emulation of performance with a real-time controlled test bench. The test equipment proposed in this paper is able to emulate slope, adhesion conditions, and weather conditions by suitably commanding a load generator/motor drive. The paper shows the design and test of a drive train for hybrid traction systems, based on real-time control system. The system outfits one half car of a hybrid vehicle. Both Hardware and software sections are included by the test bench. For obtaining system software control, the motion which regulate the interaction between the wheels and rolling surface, have been studied and implemented. The software implements the dynamical model of the vehicle and the road/wheel interaction. This test equipment have advantage of testing electric drives without prototyping the whole vehicle.

Shabbir and Evangelou [40] investigated the efficiency of a continuously variable transmission with linear control for a series hybrid electric vehicle. This paper explores the effectiveness of a CVT in a series HEV where only the motor drives the load. CVT in case of parallel hybrid vehicle doubles its role by acting as the power split device between the engine and motor [41]-[42]. In series HEV, motor provides all the propulsion in the vehicle, so the performance of CVT is independent from the choice of supervisory control system (SCS) for power train energy management, which is in contrast to parallel HEV where the wheels are mechanically connected to both the engine and the motor and thus the performance of CVT strongly depends on choice of SCS. Simulation results showed that fixed transmission leads to very high permanent magnet synchronous motor (PMSM) frictional losses during low-speed driving and very high PMSM resistance losses during high-speed driving, while as CVT keeps both the losses low for any driving type. With this, the PMSM operating point is maintained close to optimal point in terms of rotor speed and torque. By this, the overall energy consumption of the motor is reduced by 9.38%, thus leading to significant fuel saving.

Sun et al. [43] presented a paper on electric brake of a Series-Parallel HEV. Integrated brake system with an electric consuming brake subsystem and advanced strategy is proposed for the sake of high-efficiency energy recycling and brake security for series-parallel HEV. A typical characteristic of HEV is recycling of brake energy which provides security and save the energy of whole vehicle. A lot of researches are primarily carried out on brake energy recycling, ranging from cooperative control [44]-[47] of regenerative brake and friction brake to the dynamic performance analysis in brake process [48]-[50]. However these traits of vehicle brake control use mechanical friction brake instead of electrical brake, this results waste of all brake energy as well as reduce the working lifetime of the mechanical brake. In this paper, complex integrated brake system with electric consuming brake subsystem is used which can effectively protect the battery. Simulation analysis is also carried in view of the complexity and dynamic characteristics of different brake conditions.

IV. CONCLUSION

Hybrid electric vehicle has become a research hotspot due to rising price of fossil fuels and environmental problems. Environmental and economic issues are providing a desire to develop and produce clean and efficient vehicles. Various projects are gonging on to develop the technology. The aim of this review paper to explain the HEV in detail and the advantages and disadvantages of new technologies used. Some

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related topics like energy management, fuel economy, and power management strategies are considered. Descriptive view of overall HEV is done to advance HEV technology and creativity. This paper doesn't conclude with a single method to improve HEV technology but advocates mixing more than one to compensate for each own deficiencies. The continuous development in the field of technology for HEV will lead to, use of HEV for future transportation.

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