A Review on the Development in Hybrid Electric Vehicle

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Abstract— The paper aims at reviewing the history, the development, and the current scenario of hybrid electric vehicle (HEV). HEVs have their origin back in the mid-nineteenth century and even though it had gone through a lot of ups and downs, today it is at a revolutionary stage. Presence of an alternative energy source along with the Internal Combustion Engine (ICE) in Hybrid Electric Vehicles (HEVs) appeals for optimal power split between them for minimum fuel consumption and maximum power utilization. Hence HEVs provide better fuel economy compared to ICE based vehicles/conventional vehicle. Energy management strategies are the algorithms that decide the power split between engine and motor in order to improve the fuel economy and optimize the performance of HEVs. This paper describes various energy management strategies available in the literature. A lot of research work has been conducted for energy optimization and the same is extended for Plug-in Hybrid Electric Vehicles (PHEVs). This paper concentrates on the battery powered hybrid vehicles. Numerous methods are introduced in the literature and based on these, several control strategies are proposed. These control strategies are summarized here in a coherent framework. This paper will serve as a ready reference for the researchers working in the area of energy optimization of hybrid vehicles.

Keywords: Electric Vehicle, ANFIS, Phevs, Energy Optimization

I. INTRODUCTION

Hybrid Electric Vehicles (HEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) consist of two power sources, that is, (1) Internal Combustion Engine (ICE) and (2) battery. Power split between these two is of utmost importance to minimize the fuel consumption without affecting the vehicle speed[1]. The literature reveals that various power split strategies have been developed and implemented. These strategies vary in optimization type (global or local), computational time, structural complexity, a priori knowledge of driving pattern, and effectiveness of the algorithm. A survey of these available methods would be of great use for researchers and practitioners working on HEVs/PHEVs.

Another possible approach for extending the electric range of an HEV is to allow continuous charging of the battery while running[2]'. The emergence of solar-driven HEVs (PVHEVs) leads to continuous charging of batteries by means of solar energy, which minimizes the usage of gasoline and hence reduces environmental pollution.

A number of hybrid electric drive train topologies exist, such as the series, the parallel, and the combined (or series-parallel) topology. Within each topology, a number of variants exist. This HEV power train is of the series-parallel type, such as the one found in the Toyota Prius car. This HEV has two kinds of motive power sources: an electric motor and an internal combustion engine (ICE), in order to increase the drive train efficiency and reduce air pollution. It combines the advantages of the electric motor drive (no pollution and high available power at low speed) and the advantages of an internal combustion engine (high dynamic performance and low pollution at high speeds).

Robust and affordable batteries are a primary challenge for hybrid vehicles. Various HEV battery compositions have been tried in the past with the best results from lithium-ion derivatives. Three levels of integration of battery packs are possible in vehicles: (1) singular battery cells, (2) modules, comprised of individual battery cell, and (3) battery packs, comprised of modules. Battery should be able to supply high power over short periods and must be capable of enduring millions of transient shallow cycles over vehicle life. To extend the range and life of a battery, it can be interfaced with an ultracapacitor (UC) which permits longer life cycle, higher rate of charge/discharge and lower internal resistance which result in lesser heat loss and better reliability. UC improves the efficiency cycle to around 90% from 80% [3]. The combination of battery and UC forming a hybrid energy storage system (HESS) is more efficient as compared to their individual performances.

II. HYBRID ELECTRIC VEHICLES

Conventional vehicles run on internal combustion engines, consuming fuel to deliver the required power[4]. In addition to providing a useful work, conventional vehicles are encountered with dissipative energy, such as the braking energy, aerodynamic drag losses, tire friction losses, and engine idling losses. In this topology, emission reduction possibilities exist, such as lighter materials and more improved designs, but are limited. For instance, while

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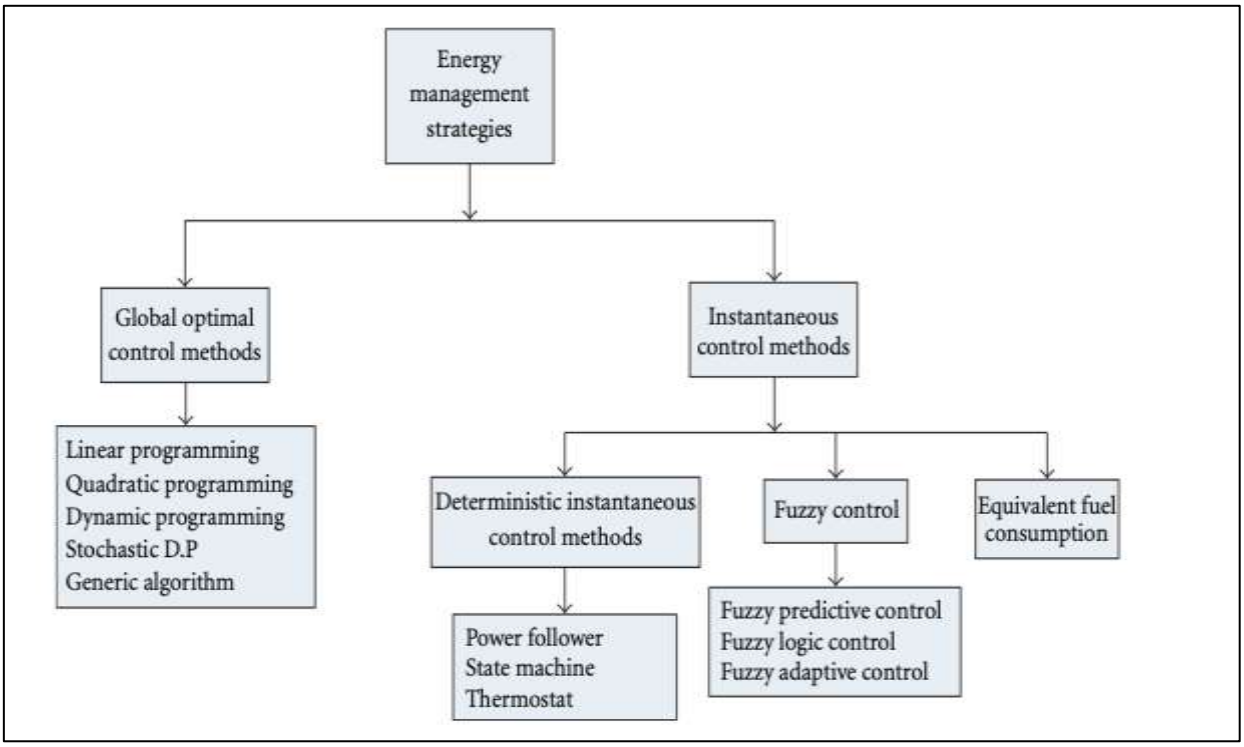

Fig. 1: Energy management control strategies for HEV.

reducing further the aerodynamic drag or the tire losses is possible, braking and idling losses will always be significant in conventional vehicles. Nevertheless, the sizing of the combustion engine will always be decided by the power it needs to provide. To circumvent this limitation, various hybrid architectures have been developed, where each architecture has its advantages and disadvantages[5].

Hybrid vehicles combine two or more technology principles to produce, store, and deliver power[6]. Current market hybrid vehicles typically combine a combustion engine and an electric machine (EM), as power converters, and they are referred to as HEV's. This hybridization allows a wide variety of topologies for the configuration of the powertrain.

When a series HEV is used in highway or interurban driving, high powers need to be transmitted to the wheels from the EM[7]. Hence, large electrical machines are needed to achieve high vehicle speeds. In addition, this topology requires a double energy conversion for delivering the required power, which induces efficiency losses. In this configuration, the size of the traction EM is deducted from the vehicle's required performance (such as the acceleration requirement). Thus, the sizing of the power- train reduces to finding the optimal sizing of the battery and the power generating group (combustion engine/generator)[8].

A. Parallel hybrid

The grey squares represent differential gears as displayed in figure 1. Parallel hybrid systems have both an internal combustion engine and an electric motor that can both individually drive the car or both coupled up jointly giving drive [9]. This is the most common hybrid system as of 2016.If they are joined at an axis (in parallel), the speeds at this axis must be identical and the supplied torques add together. (Most electric bicycles are of this type.) When only one of the two sources is in use, the other must either also rotate, be connected by a one way clutch or freewheel.

With cars the two sources may be applied to the same shaft (for example with the electric motor connected between the engine and transmission), turning at equal speeds and the torques adding up with the electric motor adding or subtracting torque to the system as necessary. (The Honda Insight uses this system.)

In parallel HEVs, the combustion engine and the EM are both connected to a mechanical transmission, and they can generate power independently of each other[10]. The EM can be connected before or after the transmission, as shown in Fig. 2 with (a) and (b). Moreover, the HEV can switch between the power sources given the driving conditions. In this configuration, there is no separate generator. Whenever generating power is possible and needed (e.g., energy recuperated from braking), the EM functions as a generator[11].

B. Series hybrid

Structure of a series-hybrid vehicle. The grey square represents a differential gear. An alternative arrangement (not shown) is to have electric motors at two or four wheels.

Series hybrids are also referred to as extended-range electric vehicles (EREV) or range-extended electric vehicles (REEV). (Series hybrids with particular characteristics are classified as range-extended battery-electric vehicle (BEVx) by the California Air Resources Board.

Parallel HEVs have a direct mechanical connection between the engine and the wheels. This leads to smaller energy losses (as they do not require the dual energy conversion as the series topology) but less flexibility in the mutual positioning of the powertrain components compared with the series HEV drivetrain as well[12].

Series–parallel HEVs have an extra direct mechanical connection between the generator and the traction

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motor via the transmission. These architectures combine the benefits from both series and parallel HEVs. They are usually constructed with one or more planetary gear sets (PGSs) and require at least two EMs. PGSs are transmission elements with three connectivity points (ring, sun, and carrier). These transmission elements eliminate the need of a traditional stepped (manual or automatic) gearbox and other transmission components[13].

Due to their increased flexibility in operating the components (as in series HEVs) and the presence of mechanical links (as in parallel HEVs), series–parallel HEVs can lead to a reduced fuel consumption for a wide variety of applications [14]. However, at the same time, they come at a higher price and require more complex control strategies[15].

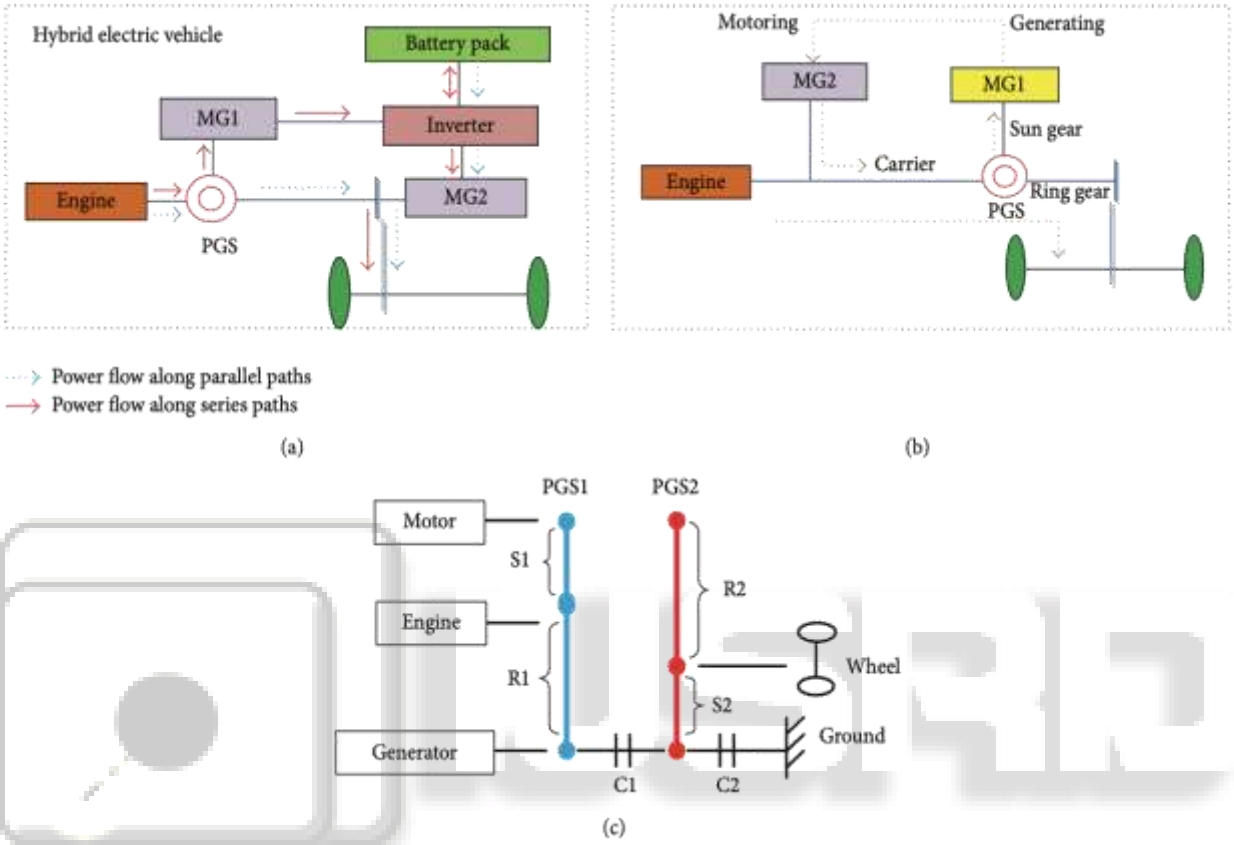

Fig. 2: Power-split configurations: (a) input split, (b) output split, and (c) compound split.

III. Configurations, Main Issues, and Control of HEV

A. *Configurations of HEVs.*

According to technical Committee 69 (electric road vehicles) of the International Electro technical Commission, an HEV is a vehicle in which propulsion energy is available from two or more kinds or types of energy sources or converters, and at least one of them can deliver electrical energy . Based on this definition, there are many kinds of HEVs, for example, battery and ICE, battery and capacitor, and battery and flywheel. However, the above definition is not accepted by ordinary people. Generally, they think that HEV is a vehicle having electric motor and ICE, thus this general definition is adopted in this paper. Traditionally, HEV can be classified into three types: series HEV, parallel HEV, and combination HEV . Figure 3 shows the configurations of HEV, arrow represents the direction of the power flow.

1) Configuration of Series HEV.

From Figure 3, we can see that the series HEV is composed of ICE, generator, power converter, motor, and battery. There is no mechanical connection between ICE and transmission, thus ICE can operate at maximum efficient point by regulating the output power of battery to satisfy the required power of vehicle. But, the energy from the ICE transmits via generator and motor, so much more energy will be lost. Since the motor is the final and sole drive device, the motor must be larger enough to satisfy performance of vehicle, and thus the regenerative braking power almost can be stored in battery by motor.

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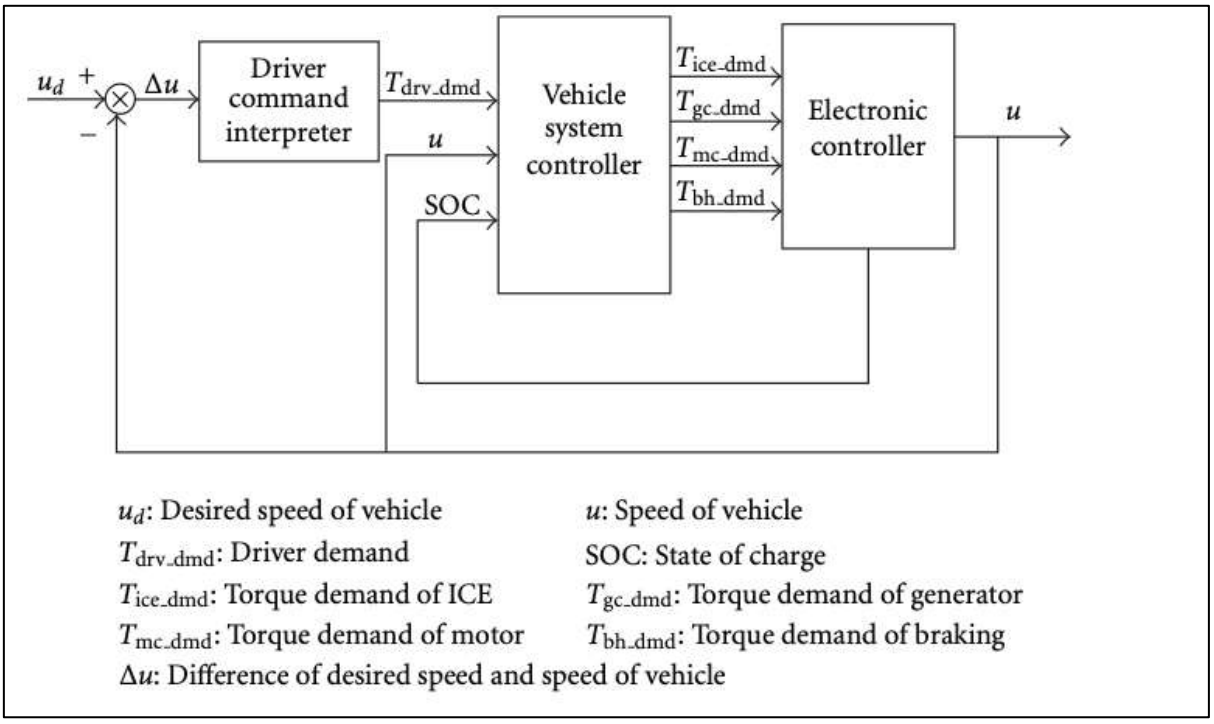

Fig. 3: Block diagram of HEV controller.

B. Main Issues of HEV.

Compare to conventional vehicle, HEV can save fuel for the following reasons.

1) HEV can store part of the vehicle's kinetic energy in battery while braking or downslope in which other- wise is burnt in the brake drums in the form of heat in conventional vehicle.
2) The ICE in an HEV can be designed with a smaller displacement without compromising the performance of vehicle.
3) HEV can make ICE operate at maximum efficiency point or optimal operating line by regulating the out- put power of battery to satisfy the required power of vehicle.
4) HEV is a multiple energy system; the main issue of HEV is how to optimize the power flow to obtain best fuel economy or low emission at lower cost, which is often referred to as the energy management (EM) problem. The issue will be discussed in next section in detail.

IV. Problem Overview

The presence of two power sources focuses on the need of designing an energy management strategy to split power between them[16]. The strategy should be able to minimize the fuel consumption and maximize the power utilization. In HEVs, the battery is a supporting power source which gets charged when ICE powers the vehicle and also through regenerative braking. In HEVs the state of charge (SOC) of the battery is the same at the start and end of the trip; that is, it works in charge sustaining mode. In PHEVs, the batteries are charged through mains; therefore it can be depleted to the permissible minimum level at the end of the trip; that is, it works in a charge depletion mode[17]. PHEVs may call upon to work in charge sustaining, charge depletion, or combination of both based on the requirement.

V. Overview of Different Optimization Strategies

Due to the complex structure of HEVs/PHEVs, the design of control strategies is a challenging task. The preliminary objective of the control strategy is to satisfy the driver's power demand with minimum fuel consumption and toxic emissions and with optimum vehicle performance. Moreover, fuel economy and emissions minimization are conflicting objectives; a smart control strategy should satisfy a trade-off bet- ween them[18].

Various control strategies are proposed for optimal performance of HEVs/PHEVs. The strategies published till 2012 are reviewed and categorized here. A detailed overview of different existing control strategies along with their merits and demerits is presented. A broad classification of these strategies is given in Figure 3. All these strategies are compared in terms of structural complexity, computation time, type of solution (real, global, and local), and a priori knowledge of driving pattern[19].

There is no commonly accepted answer for "structural complexity" but the intersection of almost all answers is nonempty. Structural complexity deals with the complexity classes, internal structure of complexity classes, and relations between different complexity classes. Complexity class is a set of problems of related source-based complexity and can be characterized in terms of mathematical logic needed to express them. Computation time is the length of time required to perform a computational process[20].

A controller designed for a particular set of parameters is said to be robust if it performs fairly well under a different set of assumptions. To deal with uncertainty, robust controllers are designed to function properly with uncertain parameter set or disturbance set[21].

Local optimal of an optimization problem is optimal (either maximal or minimal) within a neighbouring set of solutions. A global optimal, in contrast to local, is the optimal

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solution amongst all possible solutions of an optimization problem[22].

Control strategies are broadly classified into rule-based and optimization-based control strategy and all other sub categories are classified based on these two main categories.

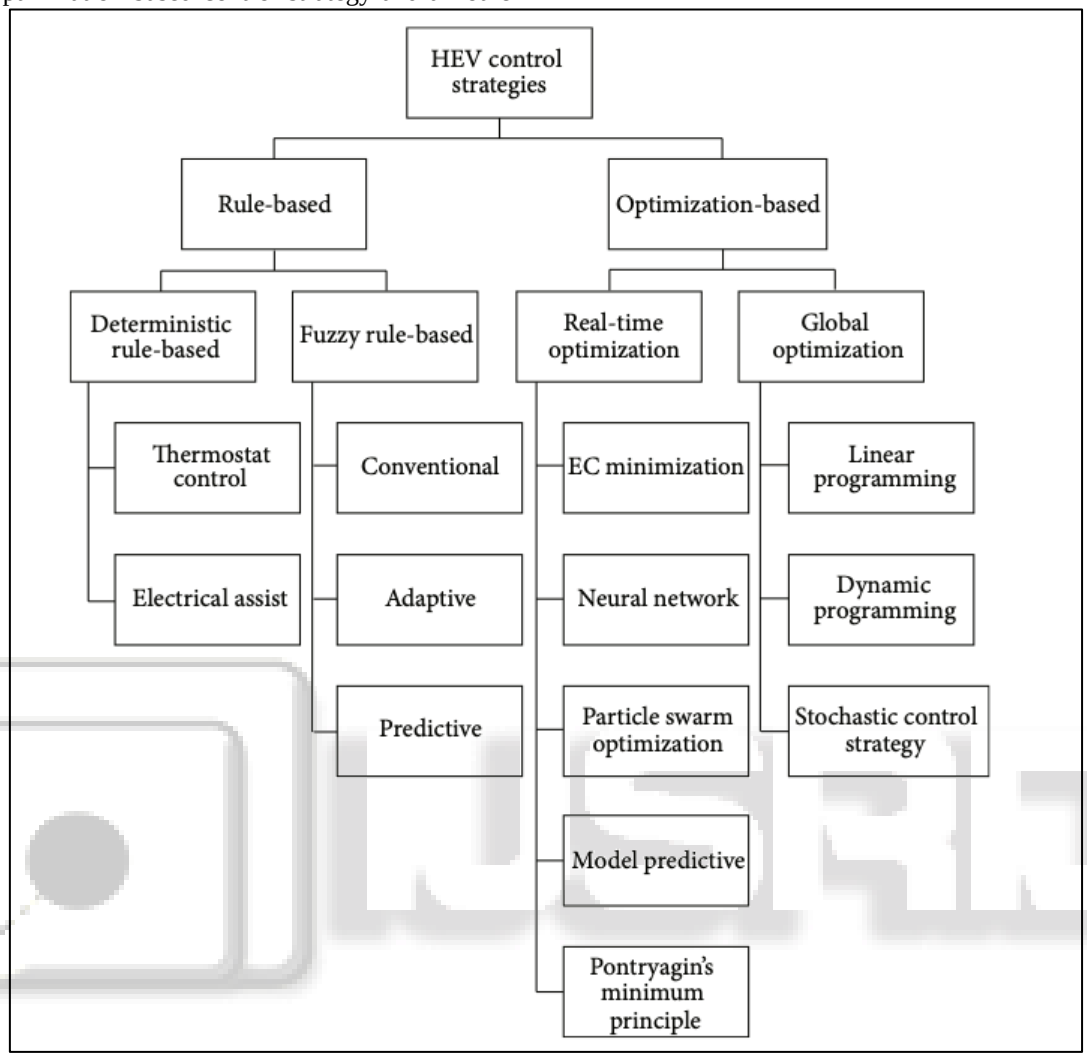

Fig. 4: Classification of control strategies.

VI. Conclusion and Future Direction

As HEVs are gaining more popularity, the role of the energy management system in the hybrid drive train is escalating. A thorough description and comparison of all the control strategies to optimize the power split between the primary and secondary sources of HEVs/PHEVs used are given here. Evolution of control strategies from thermostat to advanced intelligent methods is included in the study.

Rule-based controllers are easily implementable, but the resultant operation may be quite far from optimal; that is, the power consumption is not optimized for the whole trip. In order to achieve the global optimality a priori information of trip is required. Although real-time energy management is not directly possible using optimization-based methods, an instantaneous cost function based strategy may result in real-time optimization. The strategies discussed in this paper are real-time implementable and are robust in nature. Table 1 is the concluding table and serves as a guide to choose the correct method of optimization. It is suggested that strategies should take less computational time, provide global optimal results, and get fit to the dynamic simulation environment.

To obtain reduced liquid fuel consumption and larger electric operating range without compromising with the speed and performance of vehicle, a new technology, that is, a PHEV, is in practice globally. PHEVs' charge depletion mode of operation is desirable, but a blended mode of operation

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