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Control strategies for energy management system in electric vehicle using high-level supervisory control

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Abstract

Energy Management System (EMS) is a computer-supported device utilized by drivers of electrical frameworks to maintain management and to optimize the efficiency of transmission systems. In this paper, a control strategy for EMS using on the High-level Supervisory Control (HLSC) has been reviewed. This HLSC strategy with an intelligent management algorithm technique has been evolving rapidly particularly in EMS for Electrical Vehicles (EVs). Their revolutionary applications provide efficient control strategies for EMS that increase capabilities, efficiency and accuracy, as well as reducing energy consumption in EVs. Applying EMS with HLSC control strategy with an intelligent management algorithm that is able reallocate the electrical power flow inside the EVs system to boost power efficiency and obtain optimum effectiveness. Such innovative solutions can enhance the efficiency of smart EMS in EVs as the future sustainable transportation.

Keywords: Energy management system; Electric vehicle; High-level supervisory control; Rule-based control; Optimized-based control

1 Introduction

Global temperature changes and air pollution are among the obstacles faced by today's society, which influence our beliefs in brand new technical innovations. Major eco-friendly modifications must be created at each degree of innovation and in each market. For the automotive market, this situation indicates that our principal method of transportation, now mostly based on the Internal Combustion Engine (ICE), has to introduce modifications to sustain a well-maintained atmosphere [1,2]. Among the available options is the electrification of automobiles, such as vans, motorcycles, buses, and trucks. Hybrid Electric Vehicles (HEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) are the primary steps to create the switch to Battery Electric Vehicles (BEVs) within the automotive sector.

EVs have presented an excellent alternative to reduce the consumption of petrol and other high CO_2 emitting transportation gases. However, one primary constriction with EVs is the functionality of batteries to offer electricity for a driving range that approaches petrol-sustained vehicles. This insufficiency creates span stress to potential EV drivers. Different attempts were made consisting of HEV and PHEV that combine a small ICE to obtain better gas mileage [3,4]. For that reason, primary importance is placed on electricity monitoring of the EV system. The vehicle path prediction that applies the product line tracking procedure, which uses either true or anticipated vehicle rate and road grade paths, could help in getting a superior power application.

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The body of an EV requires the unit of electricity control, which is primary and essential. An Energy Management System (EMS) is a computer-aided resource that drives the electrical power grids to monitor, command, and improve the generation and functionality of the gear box device. In an EV, EMS is categorised into three levels of management, namely low-level control (LLC), low-level component control (LLCC), and high-level supervisory control (HLSC) [5].

In the 1970s, the initial research on the EMS for EVs was released, and then, by the 1990s, research on the EV power monitoring system was published. As it can affect the electronic components and the efficiency sizing of the EVs, EMS is considered to be a crucial issue. Lowering the consumption of energy, minimizing exhausts, reducing the operating cost, reducing noise pollution, boosting steering functionality, and simplifying usage are the benefits that can be gained by improving the electricity management in EVs [6]. This objective can be achieved by observing and understanding drivers' behaviour, ecological and vehicle ailments, and regulating the procedure for EV usage by utilizing intelligent power monitoring methods.

2 Energy Management System

Energy Management System (EMS) is a computer-supported device utilized by drivers of electrical frameworks to maintain management and to optimize the efficiency of transmission systems. EMS can be categorized into three levels which are hardware-based low-level command, hardware-based low degree element command and software-based high-ranking regulatory command [7]. These commands collaborate in digital units during the analysis, application, and completion of the EMS tactic.

The 3rd phase control strategy is the HLSC, which is composed of event-based or even time-based disorders that coordinate the part amount procedure in order to boost the overall vehicle efficiency and energy consumption [8]. An intelligent management algorithm is used to enhance reduced amount part control given that an EV is regarded as a structure and a distinct compelling system considering that records modifications take place regularly.

HLSC is located on describing a cost feature which sums all the unbiased features to be decreased [9]. Consequently, high-level control strategies can be classified into four groups as can set out in Figure 1.

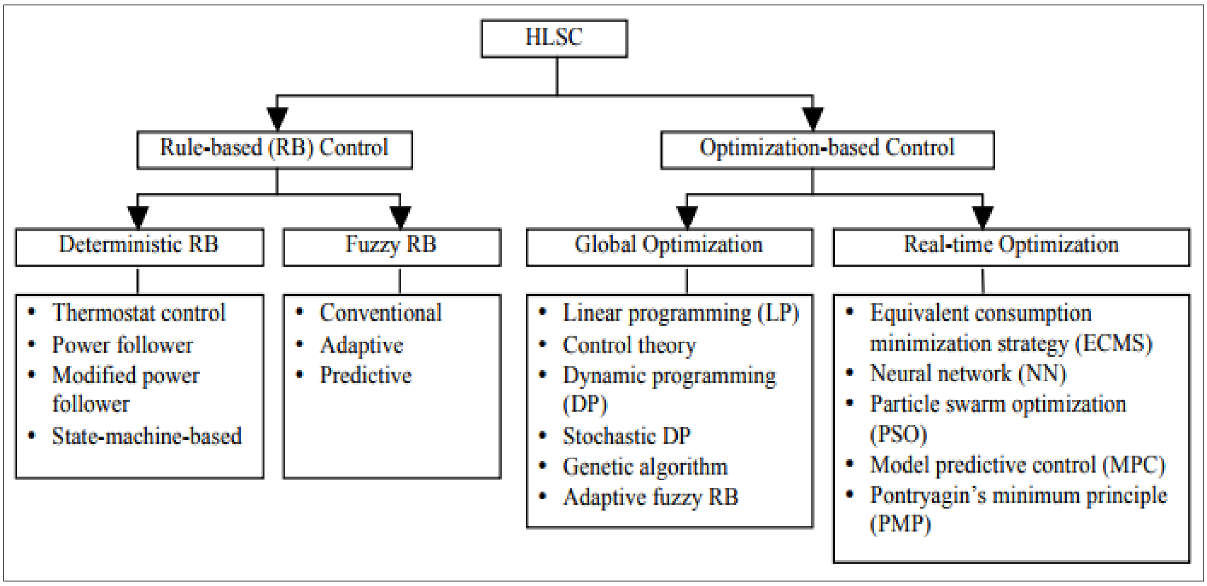

Figure 1 Classification of HLSC strategies [10]

3 Rule-Based Control

Rule-based (RB) operators contain a collection of regulations that are predefined with no anticipation of the trip. These regulations are more calibrated utilizing vehicle simulations [11]. Rule-based operators may be promptly used as real-time treatments; however, they do not guarantee the optimum activities of the powertrain components [12]. There are two main types of RB controllers which are deterministic RB, and fuzzy RB operators.

3.1 Deterministic Rule-Based Control

Generally, both rule-based (RB) management procedures are in algebraic, heuristic, and human knowledge, with logical relevant information of a predefined driving cycle [7]. Deterministic RB operators are subdivided into two styles: the temperature command strategy and the power fan technique [9,10].

The standard deterministic RB approach is the thermostat control strategy where the motor is activated and deactivated to preserve the electric Battery State of Charge (SoC) within predefined restrictions. Many scholars have examined the use of a thermostatic deterministic RB method to control HEV and BEV, which proved to be a workable and efficient strategy in real-time [11]. However, this strategy is incapable of satisfying the vehicle power demands under all operating conditions. The commonly used deterministic RB controller is the electric assist or power follower strategy. Using this strategy, the engine is the sole power supply, and the electric machine supplies additional power whenever needed by the vehicle. The Toyota Prius and Honda Insight HEV implemented this strategy. The main drawback of this strategy is that the efficiency of the whole drivetrain is not optimized [13].

3.2 Fuzzy Rule-Based Control

Fuzzy rule-based controllers are an extension of the deterministic RB control strategy. However, the rules here are not mathematically precise. The core of fuzzy RB control is that it is based on approximation rather than precision, making it tuneable and adaptive to some extent [10]. The simplest type of fuzzy RB controller is the traditional fuzzy control. It is developed to force the engine to operate on its optimal efficiency line using load balance by means of the electric machine [9]. Its main drawback is that it can only be considered optimal for specific drive cycles. There are two other types of advanced fuzzy logic control, namely adaptive fuzzy logic and predictive fuzzy logic; both can be allocated into optimization-based control.

The adaptive fuzzy RB control can combine two conflict objectives such as power economy and power load; this confliction prevents both objectives from being completely optimized. However, this results in a combination of sub-optimal solutions, depending on the weighting factors considered for each objective [14]. The predictive fuzzy RB control is not based on prior knowledge of the trip; however, it is a real-time control based on data collected using the global positioning system (GPS) [15]. Recent studies have examined the utilization of predictive fuzzy control to take care of the electrical power circulation in a set HEV in order to improve the SoC of the electric battery. However, a handful of researchers have released predictive fuzzy RB control to strengthen gas economic advances or even lessen emissions [16].

Pan et al. [17] have paid due attention to the restrictions of battery electricity density and technology, where the electricity control strategies (EMSs) of battery electric powered vehicles (BEVs) constantly play an important role in lowering the electricity intake rate. In this article, a fuzzy most desirable EMS for BEVs has been proposed with equal pace being kept in mind. Several efforts were made to comprehend the most desirable electricity control for BEVs. First, the connection among the street slope and the electricity intake has been analyzed, and an equal pace has been proposed with the aid of mapping the street slope into the car pace. Besides, the using cycle has been primarily built based at the equal pace in a selected city. Second, the car has been modelled, and the good (FLC) has been followed to moderately allocate battery electricity with the equal pace as one of the inputs. Third, the genetic algorithm (GA) has been carried out to optimize the bushy controller to enhance the control efficiency. Simulation consequences display that the motor output torque has been corrected while the street slope is not zero. The discount inside the battery contemporary fluctuations and the sluggish drop in battery voltage display that the bushy most desirable approach is useful to battery life. In addition, the electricity intake rate (ECR) decreases and development the battery change with the utility of using 7.97% while in comparison with the FLC, which shows that the bushy most desirable approach has higher electricity economy.

Hussain et al. [18] have proven the energy storage system (ESS) is the principal problem in traction applications, which includes BEVs. To alleviate the lack of strength density in BEVs, a hybrid energy storage system (HESS) may be used as an opportunity ESS. HESS has the dynamic capabilities of the battery and a super capacitor (SC), and it calls for a smart EMS to enable it to function effectively. In this research, a real-time EMS is proposed, that is made from a fuzzy common-sense controller-primarily based totally low-by skip clear out and an adaptive proportional integrator-primarily based totally fee controller. The proposed EMS intelligently distributes the desired strength from the battery and SC all through acceleration. It allocates the braking power to the SC on the premise of the nation of fee. Comparative evaluation of traditional and proposed EMS changes was carried out. The effects showed that the proposed EMS decreased the stress, temperature, and strength losses of the battery.

The management system for EV (MSEV) battery pack appears to be the next step in the growth of transport technology. Lebkowski [19] reported the framework of MSEV, which was utilized for ideal control as well as monitoring of power vehicle specifications, specifically in locations of reduced ambient temperature. This device may be utilized in every form of an electrical vehicle. The function of "GSM/GPS" technologies permits remote control tracking of condition and management of vehicle battery thermal aid (enhancing electric battery efficiency as well as endurance, while lowering operating expenses), in addition to command of grid-to-vehicle and vehicle-to-grid power circulation in intelligent grid system. System functionalities were assessed on an electrical vehicle in regular roadway situations at a time period of background temperature level reaching -25 °C.

The AI strategies inside the pc board, including fuzzy logic or the intellectual system, can easily stop loss to the electric battery, which might possibly occur while making use of a reduced temperature level atmosphere while reducing tasks linked to the servicing of the electric battery pack [20]. This management system can check the weather forecast remotely and after that, it can ask the consumer to connect the vehicle to the electrical power outlet to heat the electric battery just before driving. Depending on the driver's inclination, this device is enabled to make use of the vehicle's electric battery as an electricity stream for "smart grid" apps. App of the battery's heating unit can easily boost the comfort as well as protection of passengers, together with extending the time of electric battery life [21]. This will certainly lessen the overall cost of procedures and enhance the duration between the replacements of the battery. During practice at reduced temperatures, a vehicle that has MSEV as well as an electric battery heating unit obtained a 30% higher assortment compared to a similar vehicle without such equipment.

4 Optimization-Based Control

Optimization located EMS is divided into two main sub-categories: worldwide optimization tactics, and regional optimization strategies [10]. It is located on describing a cost feature which sums all the unbiased features to be decreased [9].

4.1 Global Optimization-Based Control

Worldwide optimization models might present a globally ideal solution for a determined "price functionality". These methods require previous knowledge of the entire trip containing the course, chauffeur's activity, driving actions, and SoC [9,10]. This contributes to the difficulty of directly implementing worldwide optimization strategies, aside from their computational difficulty [12]. One style of global optimization method is linear programming, which may be used for the optimization of powertrain energy economic condition or powertrain power economic climate since this is a convex non-linear issue, yet straight shows approximate this problem into a straight one to streamline it [21].

Another type of global optimization strategy is Dynamic Programming (DP). The strategy is classified as a functional method to handle the electricity economic situation as it is effective in handling the nonlinearity design of the issue [13]. Many research studies have made use of DP as an EMS for HEVs and BEVs [22, 23,24]. Other optimization techniques such as genetic algorithm (GA) are also utilized. Several research studies used GA in HEVs and BEVs [24,25,26]. Matched up to DP, GA is a heuristic strategy, and thus, international optimality could not be obtained [9]. There are many global optimization techniques such as linear programming (LP), control theory, dynamic programming (DP), stochastic DP, genetic algorithm, and adaptive fuzzy RB.

The genetic algorithm is a procedure for dealing with both constrained and uncontrolled optimization concerns. GA is based upon the survival of the fittest, which is the process that drives biological progression [26]. GA will repeatedly modify a population of individual solutions [13,27]. During each step, GA will randomly choose individuals as parents from the population and use them to create children that are going to be used for later generations. With every generation, the overall population will change into the perfect solution. Moreover, gas can easily be administered to fix a wide array of optimization concerns that are certainly not effectively satisfied for common optimization protocols, featuring issues in which the "objective" functionality is alternate, non-differentiable, stochastic, or even strongly nonlinear. Also, gas can easily attend to concerns of combined integer programming, where some parts are limited to be integer-valued [13,28].

Panday and Bansal [29] investigated the probability of developing an optimal controller based on Pontryagin's Minimum Principle (PMP). PMP was used as a tool in optimal control theory and GA to obtain the optimal power split between engine and battery. Researchers established a fuel-efficient power control tactic for power-split hybrid electrical vehicles utilizing a modified SoC evaluation procedure through a GA. Then, the results were fed to PMP in order to decide the threshold power at which the engine can turn on the optimal values of various governing parameters. In addition, the proposed method in this process can also improve fuel efficiency. The results showed that there is a better chance of improving fuel efficiency, which was derived for different battery models, by incorporating modified and conventional SoC estimation methods. Compared to the default strategy available, this proposed EMS has higher level of efficiency.

Liu et al. [30] paid attention to the power command management of an assortment extender power vehicle, the Chevrolet Volt. The objective was to develop a robust electricity monitoring approach to lower gasoline consumption and the electric battery cost. In this aspect, this research planned a GA-located electricity management technique for the Chevrolet Volt. To begin with, the powertrain modelling was launched, where four traction function settings were specified. At that point, GA was made use of to optimize the special guidelines in the MATLAB/Simulink modelling. Different steering cycles were used to confirm the adaptability of the popped-the-question electricity control method. The end results indicated that the suggested approach transcended to the authentic charge depleting/charge maintaining (CD/CS) approach.

Ali and Söffker [12] conducted a study to improve cautions of restricted power resources and ecological deterioration. It has become important to look for alternative choices for thermic engine-based vehicles, which have become a significant source of air pollution as well as non-renewable energy. HEVs cover a several of power resources and serve as a temporary solution that complies with the functionality criteria as well as results in energy conserving and emission reducing intentions. Energy management techniques, including controlling dependable power circulation to the vehicle power are the primary innovations of HEVs. Smart energy administration techniques that can reach optimum energy handling, fitting unit errors, and matching real-time apps may dramatically enhance the powertrain effectiveness in various operating conditions.

4.2 Predictive Real-Time Based Control

The final type of EMS is the neighbourhood optimization located tactics. Such techniques have divided the worldwide optimization complications into a set of nearby optimization troubles decreasing the computational worry [9,10]. Real-time optimization-based methods like ECMS (Equivalent Consumption Minimization Strategy) are widely deployed in EVs. The ECMS defines the Hamiltonian function that mixes both the fuel and electric power price and optimizes them immediately with no prior know-how of the travel [10,31]. The Hamiltonian functionality is described based on previous information and forecasts and it must be constantly redefined.

Numerous studies have made use of ECMS as an EMS in EVs [22,23]. ECMS is a shut to optimal internet EMS that can be conveniently executed in real-time. Sustaining the battery cost is certainly not promised and it is extremely dependent on the predictive controller used, which is an expensive and challenging unit [12]. A forecast refers to the forecasting of a condition or results in the future. Real standing or end of result is unfamiliar back then when the forecast is made and may merely be predicted with a certain degree of anxiety. Therefore, in AI, energy management behaviour may be predicted using different models of uncertainty. Every model will contain different variables or parameters that can be used to forecast future behaviour. In addition, mining future outcomes will often be based on a learned previous behaviour [32].

Scherler et al. [33] examined the concept of predictive electric energy management (PEEM) as an aspect of electronic vehicle monitoring (eVM) of a BEV with a gas cell as assortment extender (RE). The PEEM distributes the on-call electric power to the electric loads. One more important functionality of PEEM is as an energy-optimised power forecast for the RE. This procedure is based upon modularisation and hierarchisation. Large units are broken down into smart subsystems that consist of mechatronic parts along with determined interfaces to connect with their environment and the plan is for all of them to be hierarchically condensed, one by one. Predicted data from the navigation body may be utilized along with vehicle models to reach a target with a specified SoC.

Liu et al. [34] analyzed battery electric vehicle energy consumption modelling. In this research, the energy consumption of a BEV was evaluated, created, and confirmed through driving examinations on public roads. At that point, the regenerative braking management strategy of the vehicle was modified to a one-pedal driving algorithm to boost its own powertrain productivity and steering experience. Ultimately, the energy consumption along an opted-for option was predicted based on the course information. An internet formula was additionally created to readjust the energy consumption forecast based upon measurements throughout steering. Ultimately, an enhanced option-looking formula was established to discover the most energy-efficient option for the specific BEV. A power-effective course that delivered a trade-off between energy consumption and opportunity saving was additionally presented. The energy consumption prophecy algorithm and the route exploring protocols were validated using likeness and driving tests on the roadway.

De Cauwer et al. [35] studied energy consumption forecast for electric Lorries based upon real-world data. The information gathered on an EV's electricity usage was utilized to design the power usage computation styles. Based upon the vehicle mechanics formula, as the rooting physical version, numerous linear regressions were utilized to build three different versions, where each version made use of a different amount of aggregation of the input guidelines. hence, enabling prophecies to use various types of accessible input guidelines. One model made use of aggregated values of the kinematic guidelines of travels. The second model also included detailed acceleration data. The third version utilized the raw records of the kinematic guidelines as input criteria to predict power usage. The prediction technique used in their research included statistical multiple regression, while the inputs for the model came from the road, environmental, and traffic situations, including the basic inputs of distance, travel time, and temperature.

Chen et al. [36] have proposed a novel predictive energy management approach for plug-in hybrid electric vehicles (PHEVs) by incorporating an online correction algorithm. A “dynamic cost function” was made use of to explain power usage as the marketing goal. A separate Discrete Particle Swarm Optimization (DPSO) formula was used to optimize the electrical power appropriation during each fifty s-interval based upon forecasts of the driving cycle. The scenario of inaccurate prophecy prediction was taken into consideration in this study and an adjustment formula was recommended to minimize the sensitiveness to the prediction precision based upon the Mamdani fuzzy logic command. Outcomes suggested that the DPSO-based anticipating energy administration technique could possibly lessen electricity intake by approximately 9.70% compared to the charge-depleting (CD) charge-sustaining (CS) electricity monitoring approach if the prophecy of the potential driving cycle is exact.

5 Conclusion

Emerging electrical power in-vehicle operations have four strategies: battery electric automobiles (BEVs), hybrid electric automobiles (HEVs), plug-in hybrid electric automobiles (PHEVs), and gas cell electric automobiles (FCVs). BEVs use electric motors and electric motor operators instead of internal ignition engines (ICEs) for power. In BEVs, the battery is the only source of power and there is no auto recharge system. As electric batteries are the major storage system in BEVs, various energy management systems (EMS) may be applied to meet the greatest effectiveness. EMS in EVs may be integrated right into the vehicle functions at three levels: hardware-based low-level control, hardware-based low-level component control, and software-based high-level supervisory control. These managements cooperate in digital units during study, application, and completion of the EMS strategy. The third stage management method is the high-level supervisory control (HLSC), which contains event-based or time-based states that coordinate the element amount function to enhance the total vehicle performance and energy consumption. The HLSC.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that is no conflict of interest of this research work.

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