Abstract

A vehicle involves many components working together intricately. The powertrain of a hybrid electric vehicle (HEV) is a link of internal combustion (IC) engine, electric motor, transmission, wheels axles, and battery pack. Each component has several parameters and possible designs. For example, a battery pack can have different capacities, chemistries, and voltages. Varying a single parameter typically affects the whole system design. Also, compatibility between different components with varying parameters must be checked. In an HEV the battery pack can be charged by regenerative braking and by excess engine power.

The battery is an essential component of the HEV and there is a need to accurately estimate its state of charge (SoC). In the proposed work the battery equivalent circuit has been modified by adding 3- RC pairs in series with the internal resistance. The values of the RC pairs have been calculated mathematically by solving the circuit model, based on charging and discharging characteristics of the Lithium-ion battery. Further, the obtained values of these parameters is optimized. The SoC of the battery is estimated using the combination of coulomb counting and open-circuit voltage methods to minimize the estimation error. The obtained SoC is further corrected for errors using ANFIS based algorithms. These obtained SoCs are compared and investigated for 3 cases, i.e., without RC/with RC pairs and then tuned with ANFIS based optimization are compared for the same load. The parameter calculation method adopted here results in an efficient and accurate model that keeps track of correct battery SoC.

A single electrical source in an HEV i.e., the battery is not enough to cover a large distance alone. Moreover, the battery is subjected to high transient due to excessive power demand based on the driving cycle. Therefore, to protect the battery from such sudden transient it is necessary to club them with other sources like ultracapacitor. Hence this necessitates the requirement of a hybrid energy storage system (HESS) for HEV. HESS is characterized by a beneficial coupling of two or more energy storage technologies with supplementary operating characteristics of each other (such as energy and power density, self-discharge rate, efficiency, lifetime etc.). The HESS plays a crucial role in increasing the fuel

economy, driving range and battery life span. HESS proposed here consists of a battery and ultracapacitor (UC). UCs provide the advantage of quick and frequent charging/discharging without degrading the battery state of health and are also used to absorb most of the energy generated due to regenerative braking. The Lithium-ion battery will provide the energy required to run the vehicle whereas the UCs will provide the above-average energy required by the motor.

The topology used here to carry out the sizing of HESS is a rule-based energy management system, which considers pre-decided threshold parameters of various storage devices. In the proposed method, a prescribed set of limiting values of current and voltages have been set, which help to maintain the UC voltage and battery current within range. This method reduces the above-average peaks of the required current from the batteries. Similarly, while recharging due to the regenerative braking, the proposed method removes the above-average peaks of the charging current of UCs. The proposed topology along with the Energy management strategy (EMS) provides better SoC levels, giving a 38.6% increase in the state of health levels of the batteries at the end of the driving trip.

The next most important focus of this study is to develop an energy management strategy (EMS) for optimizing the energy flow between electric motor (EM) and internal combustion engine (ICE) in an HEV. In this work, it has been ensured that both the onboard source (EM and ICE) manoeuvre in their highly efficient region. The few selected important parameters like SoC, braking energy, and demanded torque has been considered for constructing the EMS with some additional constraints. The above requirement calls for the need for an intelligent algorithm to address the problem of energy-splitting between the available sources. To address this issue, the EMS tuned using fuzzy logic, Elman neural network and adaptive neuro-fuzzy inference system have been considered in this work. The reasons for choosing and modeling these algorithms as per the requirement are as below:

(a) The fuzzy logic is robust and need no precise inputs data. The fuzzy logic can accommodate several types of inputs including vague, distorted or imprecise data. Moreover, they are computationally efficient and do not require a huge memory space.

(b) Elman Neural Networks (ENN) can learn by themselves and produce the output that is not limited to the input provided to them. They can perform multiple tasks in parallel without affecting the system performance and the most important part is that this algorithm gives the output instantaneously as per driver power demand.

(c) The adaptive neuro-fuzzy inference system (ANFIS) is robust and has self-learning capability. This algorithm combines the advantages of both fuzzy and ANN which makes it a suitable candidate for structuring the EMS for HEV application.

The above-mentioned EMS have been investigated with the power-split architecture of the HEV. The reason for choosing this configuration over series and parallel architecture is that it possesses the merits of both these architectures. However, the design of EMS for this configuration is complex compared to series and parallel HEV. It is observed that the fuel economy is higher with fuzzy logic when compared with conventional, ENN has higher fuel economy compared to both fuzzy logic and conventional whereas the fuel economy with ANFIS is at highest compared to conventional, fuzzy logic and ENN based EMS.

The above-mentioned work has been simulated in MATLAB/Simulink and advanced vehicle simulator (ADVISOR) and then, the whole system is validated in real-time on a hardware-in-the-loop (HIL) testing platform. This work employs an FPGA-based MicroLabBox hardware controller to validate the real-time behaviour of proposed schemes.