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ABSTRACT

This research work aims to presents investigate the power and Energy energy management of a battery-supercapacitors Hybrid Energy Storage System (HESS) for Electric vehicles (EVs). A battery, a set of supercapacitors and a bidirectional DC-DC converter used were employed to construct the a parallel semi-active architecture of HESS. Two strategies of Rule-Base Linear Quadratic Regulators (R-B LQRs) were proposed to manage the power flow in HESS to reduce the overall battery stress during high demand events. The Supercapacitors supercapacitors supply's the high load demand, while, the battery supply's supplies the low load demand. The HESS, EV and the proposed controllers were simulated in a MATLAB/Simulink environment. Three standard drive cycles, namely, (Urban Dynamometer Driving Schedule UDDS, New York City Cycle NYCC and Japan1015 drive cycle), were implemented to validate the controller's responses. The results of the R-B LQR controllers were compared in terms number of the possible drive cycles. According to the results achieved, This the proposed hybridization achieves stable response of the HESS current over the drive cycles, effectively reduced reducing the battery's size, and extends battery its life-time.

1. Introduction

Nowadays, the landed vehicles can be classified in to three main categories; , namely, conventional vehicles, Hybrid Electric Vehicles (HEVs) and Electric Vehicles (EVs). Currently, the eConventional vehicles with an internal combustion engine (ICE) are the most common type in today's the market. In ICEs, chemical energy (e.g. ethanol, gasoline, diesel etc.) is converteds into kinetic energy in a process have has significant power losses. On the other hand, the EV is an alternative-design automobile that uses relies on batteries battery power to provide the electricity to actuate the vehicle by an electrical motor. Furthermore, The HEV is powered by two types of energy sources, namely, ICE and electrical motor with ESS, ; it it combine the benefits of high fuel economy and low harmful emissions. Due to the necessity of to reduce the air pollution and harmful harmful vehicle's emissions, a high impact is given significant research has been focused on to developing the HEVs and EVs. Energy storage systems are pose a significant issue in the stand-alone applications. Batteries offer a wide range of the clean energy., Furthermore, they have high energy density and low power density due to a chemical processes to deliver and store the energy [1]. However, its the main drawbacks are low cycle-life, and long recharging times. In addition, the immediate response to sudden load changes in charging and discharging could potentially reduce the battery's lifetime. There are several kinds of chemical batteries that are currently available in the market like such as lead-acid, nickel cadmium (NiCad), nickel metal hydride (NiMH) and lithium-ion[2]. Whilst, tThe supercapacitor is another energy storage technology. , and Supercapacitors are is either an electric double layer capacitor (EDLC) or and a pseudo-capacitor, . which These differ in the ways they store energy and charge [3]. Compared to batteries, the supercapacitors have relatively low specific energy density and high specific power density. The supercapacitors were are used as auxiliary an energy storage device due to the dependence of terminal voltage on the state of charge. Nevertheless, various benefits can achieved by when using the supercapacitors as an auxiliary power source [4]. The low value of the terminal voltage is a core limit of supercapacitors, ; 2.5 volts is the maximum terminal voltage that can be provided by a single unit of supercapacitor unit. However, several units of supercapacitors are connected in series and in parallel to achieve the required operation voltage and energy capacity in by the powerful applications. Consequently, many researchers tried have attempted to develop improve the performance of the ESS by combining high power devices like supercapacitors or flywheels in parallel with the batteries. The main purpose of the a Hybrid Energy Storage System (HESS) is to extend the efficacy of each power source [5]. This paper work designs the a semi-active HESS by engaged engaging the a battery in parallel form with supercapacitors through a DC-DC converter, with the aim of to increaseing the merits of the two devices, and decrease their limitations [6].

The essential challenge in the design of a HESS for EV is to manage the current flow between the supercapacitors and the battery. The advantages and disadvantages of many topologies of HESS have been reviewed extensively in the existing literature [7, 8] Furthermore, in the literature, the HESS in the literature used several types of bidirectional DC-DC converters. Figure 1 illustrates six different topologies of HESS. Figure 1(a) presents the simplest topology of a battery-supercapacitor system. Due to the direct connection, the battery and the supercapacitors voltage terminal ~~is~~ remains the same, and the DC-DC converter is used to maintain the power flow. In this topology, the supercapacitor~~s~~ characteristics are limited. Furthermore, a full-sized ~~of~~ DC-DC converter is needed to manage the delivered energy [9]. The configuration in Figure 1(b) is widely used in the literature [10, 11]. The bidirectional DC-DC converter was placed between the DC-Bus and the supercapacitors as an interface to manage the current flow in HESS.~~- The r~~Reliability is the main feature of this topology, where the load current is not affected by the failure of the DC-DC converter. Figure 1(c) shows ~~Another~~ another configuration of a HESS~~ is shown in Figure 1(c)~~. In this topology, the power flow of the battery was maintained within a safe range via the DC-DC converter. The supercapacitor~~s~~ operational range was limited, and it responded as an energy buffer [12]. The topologies represented in Figure 1(d, f) used two DC-DC converters to manage the power flow from the battery and supercapacitors, ~~separately~~individually. These topologies require a full and medium sized DC-DC converter for every source. In addition, the loss, cost and weight are increased in ~~these~~ this topology compared ~~with~~ to the other topologies, ~~regarding to~~ in terms of the need for full-sized ~~of~~ DC-DC converters [13, 14]. The scheme in Figure 1(e) uses a parallel connection of batteries and supercapacitors via two DC-DC converters separately, and suffers from the same constrains in Figure 1(d, f).

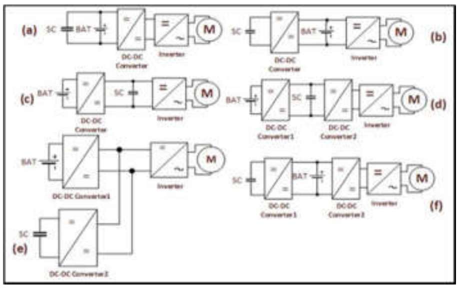

Figure 1 Most common HESS architectures [2]

On the other hand, many researches ~~were~~ present~~ing~~ed ~~the design of~~ different types of DC-DC converter designs for HESS [15, 16]. The DC-DC converter was used to manage the current flow of HESS under steady-state and transient conditions. Many researches in the literature ~~were~~ used different control algorithms to control the power flow of the HESS. In [16], the polynomial control strategy was used to manage the energy for two DC-DC converters, and the results are ~~more~~ sufficient compared ~~with~~ to the classical PI. Furthermore, ~~the new~~ recent studies ~~were~~ focused on ~~Rule~~rule-based approaches such as fuzzy logic control [17] to manage the power flow in the HESS. ~~Due to~~ The ~~the~~ accuracy ~~to~~ in measurement noise and adaptation of ~~the~~ fuzzy logic was used as an energy management strategy. However, human~~'s~~ experience was implemented to design the membership function and fuzzy rule~~;~~. ~~hence~~ Therefore, this cannot guarantee ~~good~~ suitable control performance in unexpected conditions. In [18], ~~the~~ the response of a non-linear model predictive control was compared to a ~~with and~~ linear model predictive control and rule-base control, based on the hybrid battery supercapacitors energy storage system for EV~~ in [18]~~. In ~~In o~~other work ~~the~~ aim~~ed~~ing to extend ~~in~~ battery life-cycle, a rule-based controller of HESS was compared ~~with~~ to ~~the~~ a fuzzy controller, and the results ~~proved~~ show that in transient the controllers supplied the EV load current from the supercapacitor, while the battery supplied the load during the steady state [19]. In [20], the researchers tried to extend the driving cycle and decrease the size of the HESS by using multi-objective optimization. Three standard drive cycles ~~was~~ were used to validate the proposed controller.

This research aims to design a control algorithm ~~of~~ for ~~Hybrid Energy Storage System~~ HESS for an ~~Electric Vehicle~~EV. Two control strategies of R-B LQR ~~are~~ were proposed to be implement~~ed~~ed as controllers in EV applications ~~Due~~ due to their simplicity ~~easy~~ to implement and short computation time compared with ~~the~~ to optimization methods. The limit R-B LQR aims to limit the battery current to I_{b_max} while~~,~~ the share limit R-B LQR aims to limit the battery current to I_{b_max}~~-~~, and share the load current between the battery and supercapacitor. ~~dual~~ Dual control layers ~~are~~ were used in this ~~research~~work~~,~~. ~~the~~ The rule-based approach was used to obtain the desired supercapacitors current during the load demand. ~~While t~~The LQR was used to drive the DC-DC converter by ~~manipulate~~ manipulating the duty cycle of the PWM. In addition, the LQR controller can guarantee good close-loop behavior for the DC-DC converter, and it is relatively insensitive to external disturbances, since the controller feedback gain-vector has to be determined optimally [21, 22].

This paper is organized as follows~~:~~. ~~section~~ Section 2 discusses the HESS configuration. Section 3 discusses the modeling of the HESS and EV. Section 4 contains the proposed controller algorithm. The simulation results of the proposed controller are presented in ~~section~~ Section 5. ~~While s~~Section 6 ~~summaries the conclusion~~ concludes of this research.

2. System Configuration

In EV applications, a practical HESS should be light, highly reliable, and have fast response for load variation. Due to the previous reasons, the semi-active topology in Figure 1(b) was selected to be implemented in this ~~research~~work. Figure 2 shows the semi-active topology of HESS in Matlab/Simulink. The battery model is ~~connecting~~ connected directly to the EV model as a premier energy source, and the supercapacitors model is ~~connecting~~ connected to the EV model through a DC-DC converter model as an auxiliary energy source. Three different standard drive cycles, namely, UDDS, NYCC and Japan1015, ~~drive cycle~~ were used to validate the performance of the proposed controllers.