Battery - Ultracapacitor Energy Storage System Set Up Control through Fuzzy Logic Algorithm

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Abstract. The aim of this work is to show the impact of an Energy Storage System (ESS) management on the energy transfer processes during load variations. The studied ESS includes a battery rack interfaced through a dc dc bidirectional converter with an ultracapacitor rack. The output energy is supplied to a programmable and variable resistive load. The proposed strategy based on fuzzy logic algorithm is tested and implemented on Matlab Simulink. The obtained results shown, improve the robustness of the adopted control strategy to manage the energy flow.

Keywords: Battery, Ultracapacitor, dc dc Converter, Fuzzy Logic.

1 Introduction

Energy become a strategic issue in term of social, economic and environmental contexts [1]. The increasing demand of the fossil energy has led to their rarefaction [2] and by the way an over pollution of the living space causing innumerable negatives effects on public health. For those reasons, the behavior must change moving towards the efficient use of green energy [3].

This quest for green energy has led to others compatibles systems. Electric vehicles are stakeholder. Therefore, to provide these vehicles in energy, several processes are designed. The most efficient are inevitably those that do not use a combustion engine and powered with last generation batteries [4, 5].

However, a system powered exclusively by batteries cannot be efficient because of the slow dynamic of the batteries. During accelerations the electric engine uses a strong current in a short time therefore the storage system must be very fast and powerful. To overcome this problem, an ultracapacitor rack is linked with a battery rack [6, 7]. This link will be a bidirectional current converter, which will also have the task of recovering energy from the engine during braking phases. This energy will be stored respectively in the ultracapacitor and batteries [8, 9]. This efficient topology has led to the development of increasingly affordable systems [8].

Several strategies for the energy system management are proposed in the literature [10]. In this work, an energy management algorithm based on fuzzy logic is developed, where different operation conditions are considered.

2 Energy Efficiency and Power Availability.

Widely accepted, the electric vehicle (EV) traction goes through several acceleration and breaking cycles interleaved by others cruise speed cycles, where the electrical engine is provided in energy by the own battery rack. Previously and regularly charged according to another protocol studied in [1]. During the acceleration phases, the whole of the energy is drained from the battery and ultracapacitor following an algorithm established according to the bus level voltage.

As commonly, known, during the braking phases, a substantial energy can be recovered from the load, then stored in the ultracapacitor or alternatively in the batteries. The purpose of this is to reduce the energy stress exerted on the ESS, which will increase the batteries life.

As depicted in Ragone plot shown in Fig.1 [11], a deal must be found between energy efficiency and power availability. Knowing that the power demand of an electric vehicle has a 10:1 ratio between accelerations phases and cruising speeds [9], and providing high power in short time is deadly for the battery [7]. Peukert capacity relation (1) [6] gives, the current discharge and, time discharge relationship for a battery.

$$C_p = I^k T \tag{1}$$

Where:

C_p: Peukert Capacity of the battery

I: Discharge current

T: Discharge time

k: Peukert coefficient usually 1.1 – 1.3 for lead acid battery and 1.05 – 1.2 for Nickel Metal and Lithium ion battery [7].

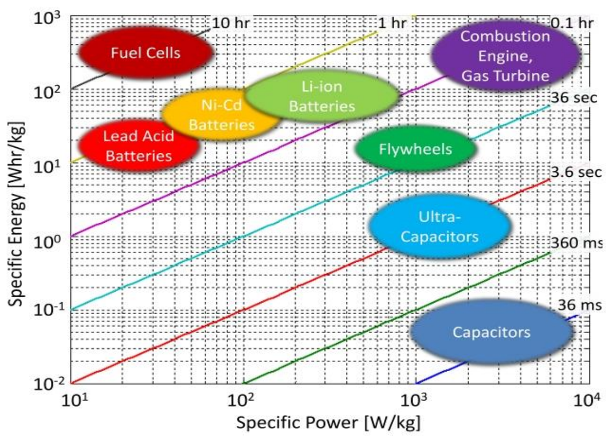

Fig.1. Ragone Plot

Therefore, a bad management algorithm can increase the destruction of the battery and reduce consequently its life. Reference [6] analyses the relation between life and high charge or discharge current for a battery.

3 Battery Ultracapacitor Hybridization Reasons

As shown in Ragone plot depicted in Fig.1 the battery has a greater energy density than the ultracapacitor based on an equal weight. However, the power availability at the same weight conditions is greater in an ultracapacitor than in a battery rack. Therefore, combining these two capabilities will increase the system efficiency.

During the acceleration phases, the ultracapacitor rack becomes in action. The traction engine must be provided by a high current in a short time corresponding to the very fast dynamics of the ultracapacitor.

During cruise speed phases and power stress less phases, the batteries come into action ensuring the availability of energy. However, the energy flow management must be much rigorous and optimal. Several solutions are presented in the literature. These solutions converge in the way of energy availability, but are often functionally different.

4 Design System Setup

4.1 System Topology

This study propose the configuration shown in Fig.2. Where a single converter manages the whole of the ESS. The battery and ultracapacitor are interconnected through a dc dc bidirectional current converter. Denote that the load is directly connected to the battery rack and the dc bus voltage, such as the dc bus voltage level is maintained in the average conditions using another dc dc converter [1].

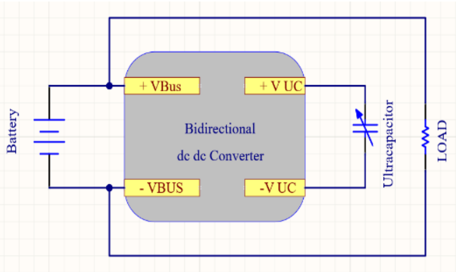

Fig.2. System Diagram

A Proton Exchange Membrane fuel cell (PEMFC) located upstream charges the battery rack following another algorithm studied in [1], thus forming a hybrid power supply. The regulated bus voltage is 42V. The battery management system is not included in this study. The power bus is maintained between 38V and 42V. In this study, it is either considered the case where the energy that will be stored in the ultracapacitor will emanate from the power bus during the relaxations phases. An algorithm based on fuzzy logic where several decisions criteria are established, and will ensure its management.

4.2 Control Strategy

The control strategy is based on a fuzzy logic algorithm, involving two input variables (Membership) and one output variable defined by the following functions depicted in Fig. 3.

Input Variables:

- Battery - BAT_FIS variable, takes into account three memberships.

- UnderVolt_B [30 30.5 34 34.5]
- MidVolt_B [34.5 35.5 36.5 37.5]
- OverVolt_B [37.5 38 39 39.5]

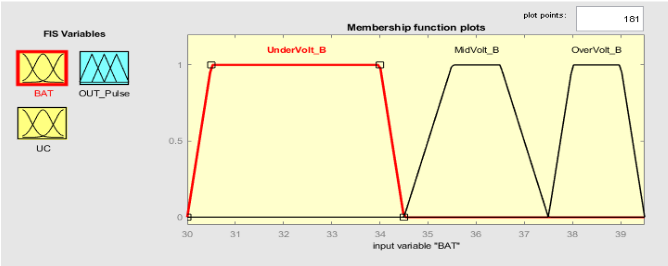

Fig.3. Battery Input variables membership functions

- Ultracapacitor UC_FIS variable, takes into account three memberships. Fig.4.

- UnderLev_UC [0 0.5 5 5.5]
- MidLev_UC [5 5.5 23 23.5]
- OverLev_UC [23.5 24 26.5 27]

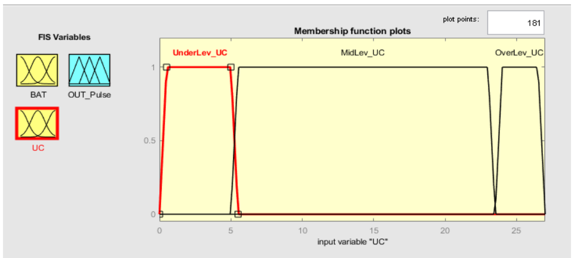

Fig.4. Ultracapacitor Input variables membership functions

Output Variables:

- **OUT_Pulse_FIS variable,** it highlights two states. Fig.5

- Buck [-0.9 -0.1 0.45 0.5]
- Boost [0.5 0.55 1.1 1.9]

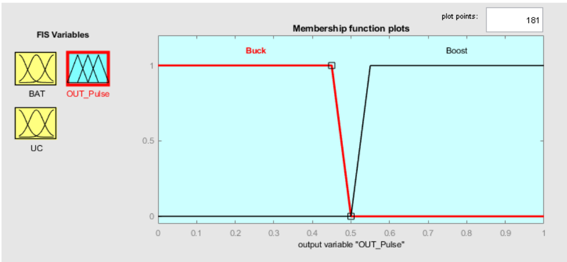

Fig.5. Output variables membership functions for converter control

The decision criteria are defined as follows.

- If (Bat under Volt_B) and (UC is OverLev_UC) then OUT_Pulse is Boost).
- If (Bat Over Volt_B) and (UC is UnderLev_UC) then OUT_Pulse is Buck).
- If (Bat under Volt_B) and (UC is MidLev_UC) then OUT_Pulse is Boost).
- If (Bat Mid Volt_B) or (UC is UnderLev_UC) then OUT_Pulse is Buck).
- If (Bat under Volt_B) or (UC is MidLev_UC) then OUT_Pulse is Buck).
- If (Bat under Volt_B) or (UC is OverLev_UC) then OUT_Pulse is Boost).
- If (Bat Mid Volt_B) and (UC is OverLev_UC) then OUT_Pulse is Boost).

The global behavioral of the fuzzy logic algorithm which control the whole of the system is depicted in Fig. 6.

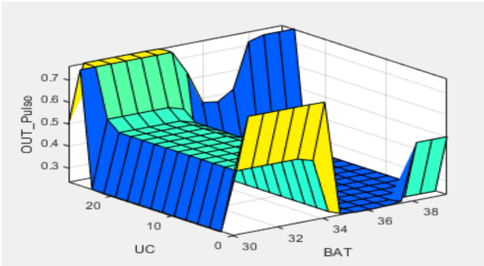

Fig.6. Global behavioral of the control algorithm

4.3 Control and Management Process

For simulation purposes, it is used a variable load model as shown in Fig.7, it will be able , then to simulate acceleration and braking phases, and see the behavior of the system various components.

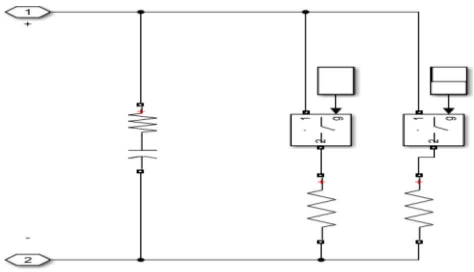

Fig.7. Variable Load Simulink Model.

As mentioned above, the bus voltage maintained between 38V and 42V is connected to the battery rack on one hand and to the load on the other hand. Fig.8. The charge and discharge of the ultracapacitor are controlled according to the power requested by the load, respecting the decision criteria set by the variables of the logic control.

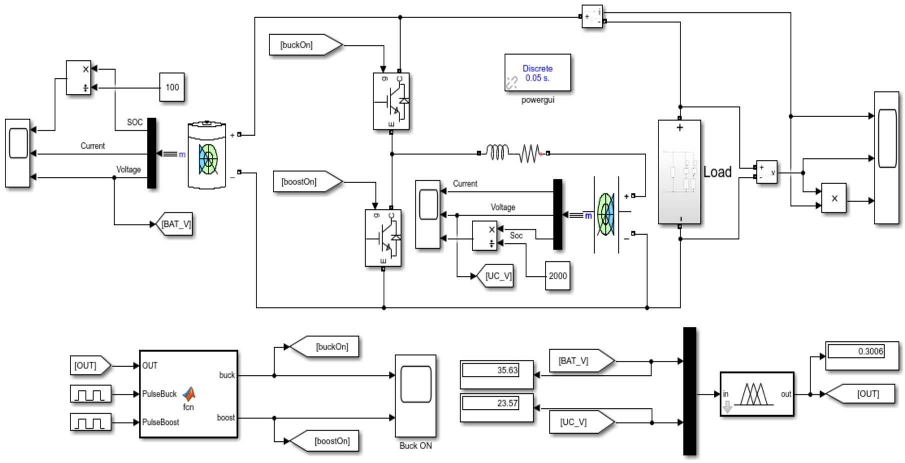

Fig.8. Simulink System Control Diagram

The bidirectional converter is made around two IGBTs transistors. The upper arm operates in Buck mode and controls the charge of the ultracapacitor under a duty cycle of 64% to limits its voltage at 27V which is the ultracapacitor rack terminal maximum voltage. While the lower IGBT arm, operates in Boost mode to controls the discharge flow from the ultracapacitor to the load bringing energy to it. The "OUT" trigger signal is generated by the fuzzy logic algorithm after analyzing the voltage level taken from the power bus.

5 Simulation Results

Fig.9 shows the simulation results obtained during load variation. It can be noted that after a sudden load variation, corresponding to an acceleration phases, the current increases rapidly causing a drop of the Battery State of Charge (SOC). The rising current will drop after the stress on the load is goes off, tantamount to deceleration phases, which will generate an increase in the battery voltage and that of the power bus.

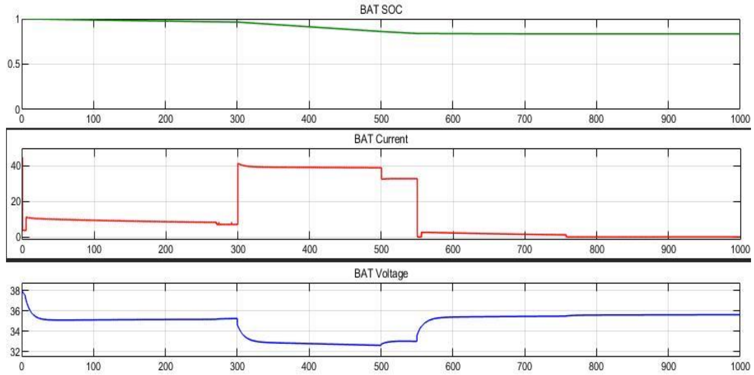

Fig.9. Battery Electrical Behavior under load variations

Fig.10 shows the reaction of the control based on fuzzy logic algorithm, which controls the converter firstly in Buck mode. Thus allows fully charge of the ultracapacitor rack to its maximum SOC. Meanwhile a stress is created on the load symbolizing an engine acceleration drawing a large amount of current that it needs, the converter switches to Boost mode and releases the power stored in the ultracapacitor, bringing current to the Power Bus. Gradually the ultracapacitor discharges causing the voltage to drop across its terminals. As soon as the constraint is lifted, the converter switches to Buck mode to allow the ultracapacitor to charge and prepare it for the next request

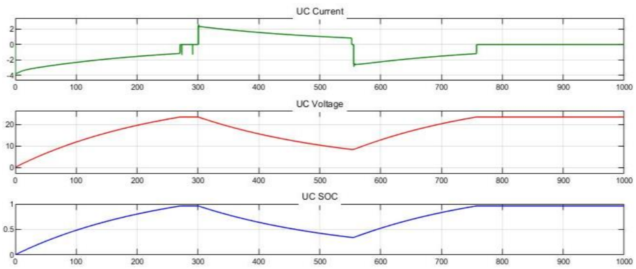

Fig.10. Ultracapacitor Electrical Behavior under load variations

In Fig.11, it is noted that the reaction of the logic control switching the converter from one mode to another allowing in Buck mode the charge of the ultracapacitor by the Bus current and in Boost mode its discharge towards the load.

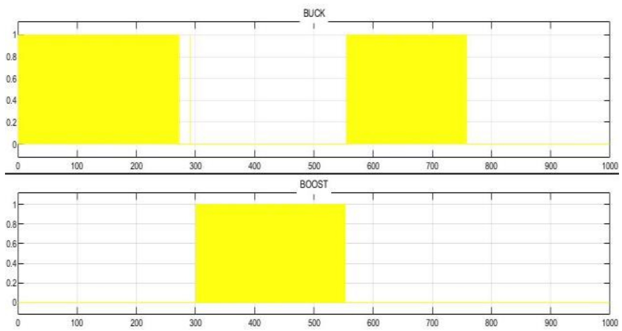

Fig.11. Converter input signals under Fuzzy logic control during load variations.

6 Conclusion

In conclusion, it can say that the algorithm works correctly since it allows the charge and the discharge of the ultracapacitor rack at the opportune moments. By acting on the switching times of the converter allowing it to operate in bidirectional mode. It can also notice that the response of the system is correct since it reacts instantly to variations in the load by preventing the SOC of the battery from falling to a dangerous threshold. Finally, this control logic algorithm allowed us to create an energetic communicating vessel between the battery rack and that of the ultracapacitor.

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