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Advanced Energy Management System For Hybrid Vehicle

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***Abstract*: The battery and ultra-capacitor hybrid storage system (HESS) is a system which can be adopted in the EV. By utilizing Ultra-capacitors, the batteries can be protected from high peak currents, which can be especially harming to the batteries. Consequently it is conceivable to expand the battery life. Battery and ultra-capacitor are connected through a bidirectional non-isolated multi input converter which has numerous points of interest. Fuzzy logic based energy management strategy is an efficient method to manage energy through HESS and furthermore regulating the SoC of ultra-capacitor while smoothing the battery power profile.**

***Index Terms*: Battery, Bidirectional non-isolated MIC, Energy management strategy (EMS), Ultra-capacitor (UC)**

I. INTRODUCTION

An electric vehicle (EV) is a vehicle which utilizes electric power to move. Its wheels are driven by electric motors. EVs were one of the primary sorts that did not utilize steed or human power. In 1830's Electric trains and cars were assembled, yet in the 1900's, there were higher number of electric cars than gasoline-powered cars. But gasoline controlled cars or diesel fuel based cars become the most widely recognized sort of vehicle for most of the last 100 years. Electric vehicles have for quite a while been utilized in some uncommon cases, for example, forklifts utilized inside a structure, golf trucks, trolley transport or certain vehicles utilized around planes at an airplane terminal. In the mid-21st century individuals are again increasingly worried about electric and hybrid vehicles an approach to reduce pollution and use less fuel.

Batteries in electric vehicles are often faced with fluctuated charging/discharging cycles which have an adverse effect on its life. One possible solution is to use a hybrid energy storage system, which combines features of ultra-capacitors and batteries. By using ultra-capacitors, the batteries can also be protected from large peak currents. In this way, by taking on the high power requirements of an EV, the ultra-capacitors may broaden the batteries' lifetime.

Also the expense of replacing the batteries is higher than the price of the additional ultra-capacitor. Thus it is preferable to use battery-ultra-capacitor hybrid storage.

In battery-UC HESS, battery acts as the primary source of energy and UC acts as the buffer system. Multi-Input Converters (MIC) is utilized to interconnect the various sources with various voltage levels.

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Among dc–dc converters used in HESS, MICs are prominent, because they are cost-effective, easy to control, & capable of controlling the energies of ESS fully [1], [2]. The objective of multi input bidirectional converter is to enhance or reduce the voltage level of the system by utilizing its ability to control power flow in either direction. An excellent controller can significantly improve the function of HESS.

There are several researches in the field of HESS. The HESS energy management strategies can be classified into on-line and off-line. Offline optimization techniques were implemented for EMS in hybrid systems; but they are inappropriate for the real- time applications. On-line energy management strategies mainly include rule-based energy management strategies, energy management strategies based on model predictions and energy management strategy of fuzzy control. In [3], [4] the fuzzy logic controller (FLC) based EMS is proposed. FLC can be merely utilized in an EMS as it doesn't need any mathematical model. Thus the proposed work aims to develop Fuzzy logic based energy management strategy for electric vehicle with battery / ultra-capacitor hybrid energy storage system.

II. BATTERY AND UC HESS

The main idea of hybrid energy storage system is to combine different energy storage technologies (e.g., batteries, fuel cells, solar panels, ultra-capacitors, etc.) into the coherent system with special control strategy, which can use the advantages of each energy source in order to improve overall performances. Special consideration should be given to the battery-ultra-capacitor HESS, where energy-dense battery acts as a source of energy for long range driving, and ultra-capacitor pack serves as a source of peak power for providing bursts of power during acceleration and it receives regenerated energy during braking.

Advantages of UC includes its large power density, higher number of charging/discharging cycles and wide range of operating temperature, which makes them ideal "assistants" for galvanic batteries in electric vehicles. A DC-DC converter with bi-directional capability is required to exchange energy between energy storage devices.The proposed system is shown in Fig 1.

For efficient power transfer, the bi-directional DC-DC converter should be light weight, compact in size and highly reliable. Depending on the isolation property, bi-directional DC-DC converters can be categorized into non-isolated bi-directional DCDC converter and isolated bi-directional DC-DC converter.

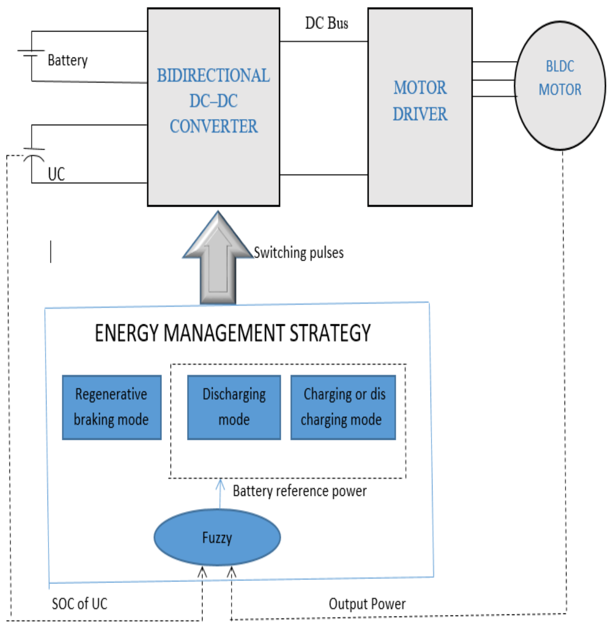
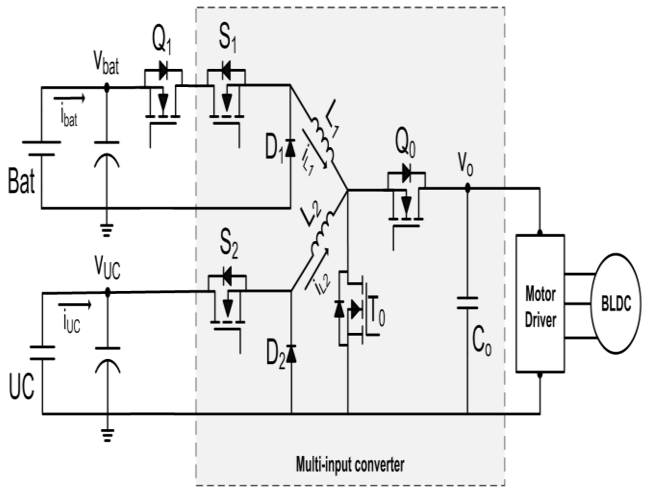


Fig. 1 : Proposed system

Basic DC-DC converter with unidirectional capability can be turned into non-isolated DC-DC converter with bi-directional capability by placing a controllable switch instead of using diode in the circuit configuration.

Bidirectional MIC [5] has three modes of operation. In discharging mode, switches S1, S2 are ON and switch Q0 is OFF.ie, during acceleration motion, both battery and UC are discharged to load. The next operating mode is regenerative mode. During braking condition, the motor will acts as generator. The generated voltage is utilised to recharge the sources. In this mode, Q0 is ON but S1 & S2 are OFF, hence the energy flows from load side to source side. The third mode of operation is charging / discharging mode. Here S1 is ON but S2 and Q0 are OFF.



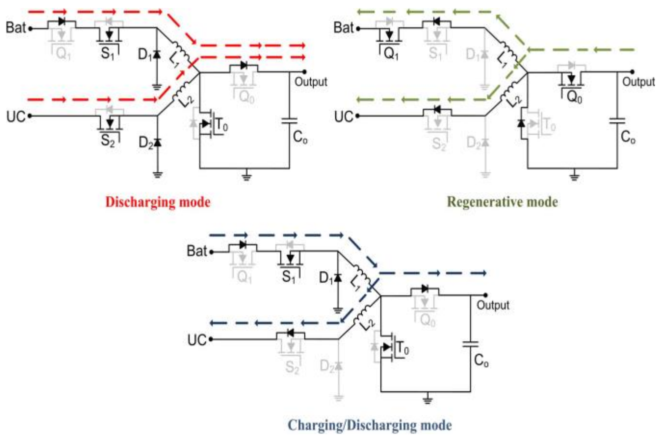


Fig. 2: Bidirectional MIC and its operating modes

This mode is initiated when the power of one input exceed the output power. Switch Q1 is added to battery to control its charging current.Q1 is assumed to be OFF. Hence during regenerative mode only UC is charged. The relationship between input source voltages and output voltage can be given for discharging, regenerative, and charging/ discharging modes as in (1)–(3), respectively,

$$V_o = V_{bat}\times\frac{d_{S1}}{1-d_{T0}} = V_{uc}\times\frac{d_{S2}}{1-d_{T0}} \quad (1)$$

$$V_o = \frac{V_{uc}}{d_{Q0}} \quad (2)$$

$$V_o = V_{bat}\times\frac{d_{S1}}{1-d_{T0}} = V_{uc}\times\frac{1}{1-d_{T0}} \quad (3)$$

Where V_0 is output voltage, V_{bat} is battery voltage and V_{UC} is ultra-capacitor voltage. For charging and charging / discharging mode ds1 is 1.In these modes the inductor currents i_{L1}, i_{L2} and voltage v_0 are given in equations (4)-(6) respectively,

$$i_{L1}(t)=\frac{1}{L_1}\int\left[v_{bat}\times(t)d_{S1}-v_0(t)(1-d_{T0})\right]dt \quad (4)$$

$$i_{L2}(t)=\frac{1}{L_2}\int\left[v_{uc}(t)d_{S1}-v_0(t)(1-d_{T0})\right]dt \quad (5)$$

$$v_0(t)=\frac{1}{C_0}\int\left[(i_{L1}(t)+i_{L2}(t))(1-d_{T0})+i_0(t)\right]dt \quad (6)$$

For regenerative mode $i_{L1}(t)$ is zero and $i_o(t)$ is negative. The corresponding $i_{l2}(t)$ and $v_o(t)$ are given in equations (7)-(8) respectively.

$$i_{L2}=\frac{1}{L_2}\int\left[v_{uc}(t)-v_0(t)d_{Q0}\right]dt \quad (7)$$

$$v_0(t)=\frac{1}{C_o}\int\left[i_{L2}(t)d_{Q0}+i_0(t)\right]dt \quad (8)$$

In order to provide the switching pulses to the converter for efficient operation Fuzzy logic based energy management strategy is proposed.

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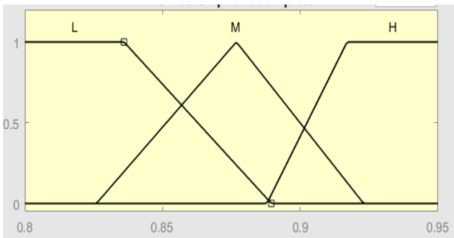
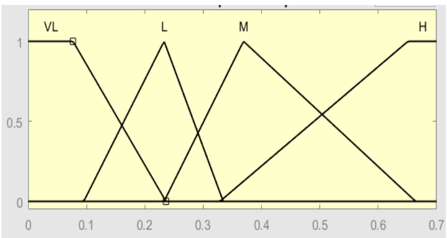
III. FUZZY LOGIC BASED ENERGY MANAGEMENT

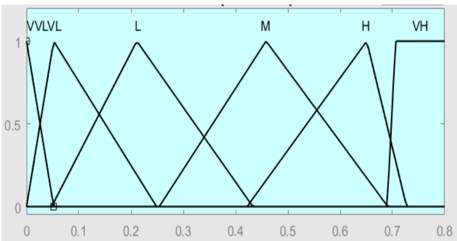
Fuzzy logic based energy management strategy (FL based EMS) can be adopted to make the battery power profile smooth and to regulate the SoC of UC. It will first find outs the mode of operation and based on which EMS generates the switching pulses. The two input fuzzy functions are SoC of UC and output power. SoC of UC has three membership functions which are Low (L), Medium (M) and High (H). Output power has four membership functions which are Very Low (VL), Low (L), Medium (M) and High (H).The output fuzzy function is the battery reference power which has six membership functions of Very Very Low (VVL), Very Low (VL) , Low (L), Medium (M) and High (H). Input and output fuzzy functions are shown in Fig 3.



(a) SoC of UC



(b) Output power



(c) Battery Reference Power

Fig.3: Input Output fuzzy variables

The universe of discourse of input SoC of UC is [0.8, 0.9] and the universe of discourse of output power is [0, 0.7]. For the output battery reference power P_b*, the universe of discourse is [0, 0.8].

If the SoC_{UC} is low and P_0 is high, it means if energy in the UC is small and output power required is more, then the battery reference power must be high. Also if SoC_{UC} is high and P_0 is low, then battery reference power is very low. Similarly, corresponding twelve rules are made as given in Table I.

Table I : Fuzzy logic rule base

SoCUC \ P0	VL	L	M	H
L	L	M	H	VH
M	VL	L	M	H
H	VVL	VL	L	M

Fig 4. Fuzzy Logic Based Energy Management Strategy Is Shown In

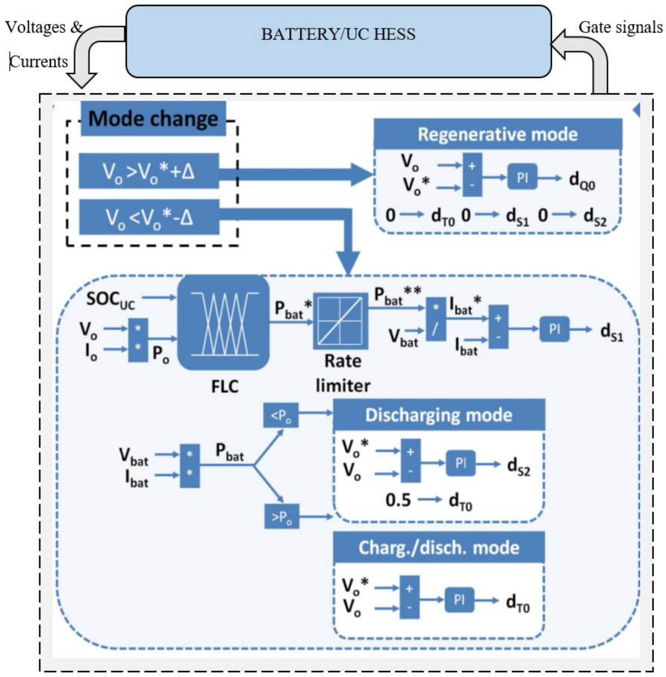


Fig.4 : FL based EMS

First step of EMS is to find the mode of operation. It determines the mode by checking the output voltage. Δ be a defined voltage level. If V_0< V_0* - Δ i.e. if the output needs to be energised, then activate discharging mode or charging /discharging mode. If V_0> V_0* - Δ i.e. if voltage is generated at the output side during braking, then activate regenerative mode. The selection of charging or discharging mode is based on the comparison between the battery and output power levels. For that, it finds the battery reference power using fuzzy logic control, a rate limiter and a PI controller. If P_{bat}< P_0 then it activate discharging mode.

And if P_{bat}> P_0 then it activate charging/discharging mode. Value of d_{T0} is set to 0.5, because high value of it may expands the input voltage range but reduces the efficiency.

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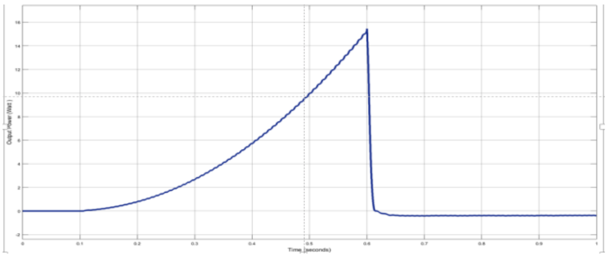
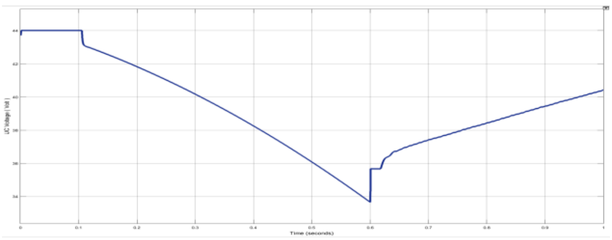
IV. MATLAB/ SIMULINK RESULTS

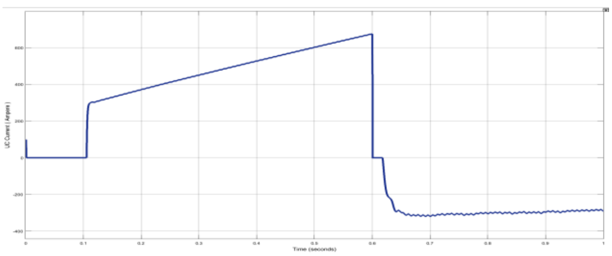
The proposed system is modelled in MATLAB environment. 110 Ah Lithium-ion battery and 29 F, 48 Volt UC is adopted in HESS. Both sources are connected to bidirectional MIC. It is then connected to a BLDC motor of power 3 KW. The input speed is given for acceleration and braking condition. Simulation results are obtained for voltage, current, SoC and power of battery and UC. During forward motion, the average power will be provided by battery and the additional peak power will be provided by UC. Also UC should have the capacity to take all the accessible braking energy. Thus battery power cycle fluctuations can be reduced and hence battery life can be extended. The simulation results are shown in fig.5. Output power, UC voltage, UC current, UC SoC, UC power battery voltage, battery current, battery SoC and battery power, are shown in Fig 5.



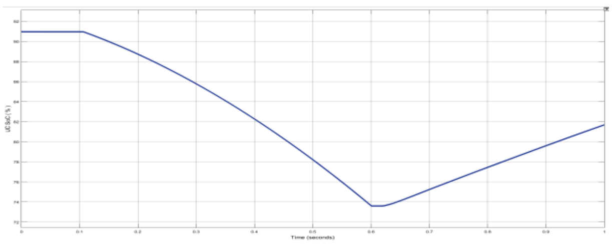
(a) Output power



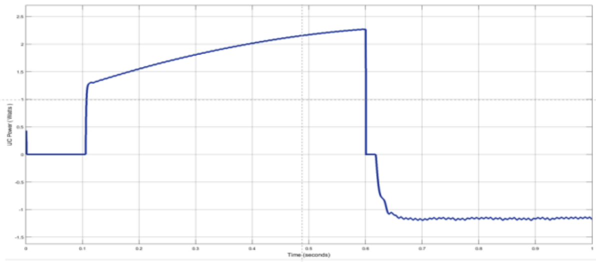
(b) UC voltage



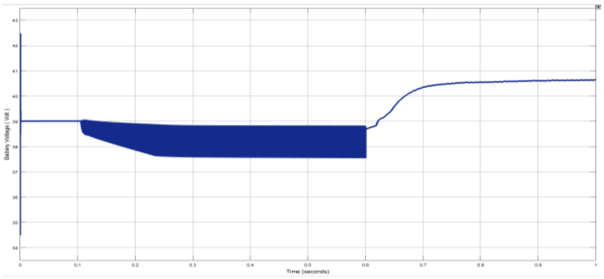
(c) UC current



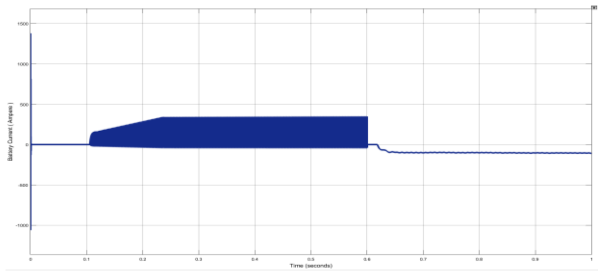
(d) UC SoC



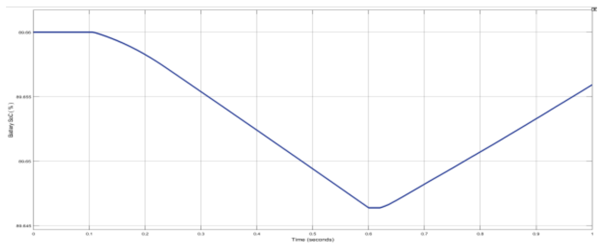
(e) UC power



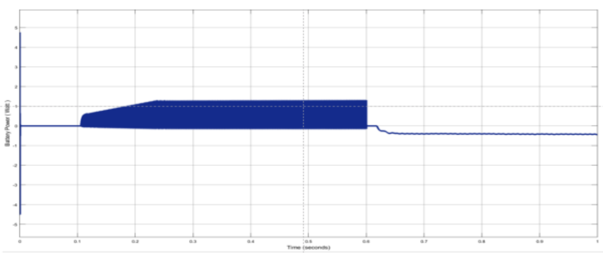
(f) Battery voltage



(g) Battery current



(h) Battery SoC



(i) Battery power

Fig.5: Simulation results

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The speed is set in such a way that from the instant 0.1 to 0.6 seconds the vehicle is accelerating and then braking occurs for a duration of 0.6 to 1 seconds. From the results it is found that, during acceleration the peak power is provided by the UC. At that time battery voltage is decreasing and the current is increasing, which means UC is discharging. The SoC of UC shows a rapid change from 91% to 73.8%. UC power Vs. Time graph shows it is discharging during acceleration. The battery voltage and battery current graphs shows that it provide average power during acceleration. There is a small change in battery SoC. From the instant 0.6 seconds to 1 seconds, the vehicle is made braking. At that time, the regenerative is captured by the UC. During braking, the UC voltage and SoC are increasing and the power is charged in the negative direction. It is charged up to 1.18 volt .But for battery, there is only a small change in voltage, current, SoC and power. Hence the battery fluctuations are reduced. Also the power profile of battery is considerably smoother as aimed.

V. CONCLUSION

An Energy Management System using Fuzzy Logic System is proposed for battery/UC HESS. This is done essentially to guarantee efficient operation of battery and UC. Since driving conditions and vehicle loads are exceedingly nonlinear and can't be expressly depicted, intelligent controllers must be utilized. Fuzzy logic based EMS offers reduced power variations of battery which will improve the battery life. During acceleration the battery gives just the reference power whereas the UC provides the additional peak power. Also during regenerative braking, UC has the capacity of fast charging. Therefore, the battery cycle life has been extended by decreasing the battery power peaks. The system controlled the SOC of UC while smoothing the battery power profile.

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