ISSN Number: 2454-2024(Online)

International Journal of Technical Research & Science

DEVELOPMENT AND ANALYSIS OF CONTROL STRATEGY FOR BATTERY TO ENHANCE THE LIFE OF THE BATTERY WITH THE APPLICATION OF ULTRA CAPACITOR

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Abstract- The present scenario, in the automobile industries, due to the battery revolution in the vehicle, the need of the hour is most important today, the battery used in the vehicles and the life of the battery, which shows how efficient the battery used makes your vehicle. The main requirement of today's industrial era is the efficiency and safe operation of the battery system. To fulfil the requirements of battery conditions, a control strategy designed for the management of energy strategy. In this control strategy, a fuzzy logic controller used with a rate limiter and this strategy implemented on a storage system for hybrid energy with the use of the bidirectional multi-input converter. The strategy shows the performance of the battery with the smooth power outline; also standardize the state of charge of the ultracapacitor. The system analyzed experimentally by the hybridization of the battery-ultra capacitor with the enhancement of the life cycle of the battery.

Keywords: Energy Management Strategy, Hybridization of Battery-UC, Rate Limiter, Electric Vehicles.

1. INTRODUCTION

According to the current scenario, it is anticipated that if worldwide petroleum resources consumed at the current consumption rate the then the petroleum resources might possible to completely exhaust within 50-70 years [1]. In this sequence, many researchers worked on the new technologies of vehicles worldwide and focused on adopting vehicles, which based on hybrid topologies instead of conventional vehicles. Today, there are many ranges of vehicles available in terms of hybrid, plug-in electric and electric vehicle [2]. The world has moved from hybrid vehicles to pure electric vehicles, many kinds of research done on increasing the efficiency of electric vehicles, and many are still going on for this purpose. Nowadays, batteries and ultracapacitors (UCs) are the universal selections for the energy storage system of electric vehicles. Generally, the energy density of a battery is high and it stores a large amount of electric energy [3-4]. On the other hand, the power density of ultracapacitor is very high and it presents a long life cycle and rapid response for charging or discharging with great efficiency. In the hybrid energy storage system (HESS), two factors are mainly responsible for the performance of electric vehicles and these two factors of HESS are, one is the power-conditioning unit and the second is energy management strategy (EMS) [5]-[6]. The energy management strategy controls the power flow between the battery and ultracapacitors in HESS because of the determination of the state of health (SOH) of battery and UC, state of charge (SOC) of UC. An optimal control based energy management strategy for the parallel hybrid electric vehicles proposed the strategy for energy sharing which minimized the fuel consumption as well as maintained the state-of-charge (SOC) of the battery within practical limits [7]. The technique searched for the minimization for wear in the battery and improved the life span of the battery. The analyzed results of the experiment after implemented the control algorithm reduced the stress on the battery and enhanced the lifespan of the battery [8]. Based on the concept of non-uniform sampling time, conversed real-time based management of power-sharing with the use of model predictive control. In this approach, a model converted into a state-space province for the buildup of this control approach. The forecasted algorithm analyzed with a rule base and constant sampling time-based strategy of control of power flow in energy storage devices [9]. The simulation results from the estimation of real-time management with the model prediction based control strategy maintained the energy and power flow efficiently and stress-free for battery therefore, the provided control schemes worked under safe operating conditions and enhanced the life span of the battery[10]-[11]. To convey the energy and power flow for an electric vehicle, a fuzzy logic-based control strategy and logic threshold-based strategy of energy control. The work of the program summarized that the Fuzzy logic-based strategy of control performed extraordinary to attain the essential analysis [12]. An optimization-based energy management strategy presented for electric vehicles to suppress the pressure on the battery at a minimum level and expand the lifetime of the battery. The rule base optimization technique is known as the Nelder-Mead simplex Method (PSO-NM) which attained the objectives of the research. With the analysis of the proposed strategy with conventional

ISSN Number: 2454-2024(Online)

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methodology obtained that the better life cycle of battery achieved [13]. To optimize the life of the battery, utilization of energy and speed of charge, a control strategy designed based on an Algorithm known as Particle swarm algorithm of optimization. This technique proposed along with steady current charging for multi sections of the system. This technique set the charge current with the algorithm and the PSO algorithm adjusted this charge current with the battery's internal resistance therefore battery reached at a superior level of effectiveness [14]-[15].

An algorithm developed to split power between two sources of energy storage and transfer the extra power with the help of a smart power converter to the pack of the ultracapacitor. This designed strategy-based model analyzed and tested on the MATLAB platform and concluded the result regarding the cut off frequency and real-time baseload shape [16]. With the vast exploitation of electric vehicles, the life cycle of the battery becomes a more considerable factor with the ultracapacitor. With the fusion of two sources battery and ultracapacitor, the operating principle of the system became expand and elastic. Therefore, an advanced concept discussed to arrange the status of charges (SOC) of ultracapacitor [17]. This advanced concept based on two stapes artificial neural network approach, which achieved the required target regarding SOC. This concept concluded that the approach fulfilled the required parameters of efficiency of storage and enhancement in the lifetime of battery [18]. The enhancement in the green revolution all over the world produced great opportunities in battery-based vehicles and contributed the most to the environment. After the researches on battery and storage devices, some refinements made by the researchers in battery technologies and control strategies for improving the health conditions of battery as well as storage capacity and efficiency of storage devices through the hybridization of battery and ultra capacitor[19]. In the vast technologies of control strategy, Vaishakh. M.Nayanar adopted the fusion of fuzzy and Proportional Integral for the manager of power and energy flow between hybrid storage devices. The whole strategy validated on Matlab/Simulink and summarized the effects of implemented strategy on the system [20]. Further, extend the theory of hybridization, battery and life cycle etc., Zhenhua Cai, discussed the fuzzy logic-based control scheme for power and energy split between storage devices. The theory discussed the health condition of battery and ultracapacitor in terms of SOC (State of Charge) and enhanced the life cycle of battery [21]-[22]. By the refinement in the technology of electric vehicles, researchers produced various theories and research methodologies on fuzzy-based concepts and elaborated the results, which provide the guidance in the research area for hybrid techniques in battery technologies. The results, which simulated in Matlab, concluded the results regarding the suppression of surge current and improved the consumption of energy tempo [23]-[24].

2. BATTERY- ULTRA CAPACITOR, A HYBRID ENERGY STORAGE SYSTEM

The Battery-UC HESS used a multi-input converter (MIC), which composed of four switches S1, S2,T0 and Q0, two power diodes D1 and D2, two inductors L1 and L2 and an output capacitor C_{out}. The MIC operated in three different modes of operation, which shown in fig.2.1 The first operating mode is discharging mode.

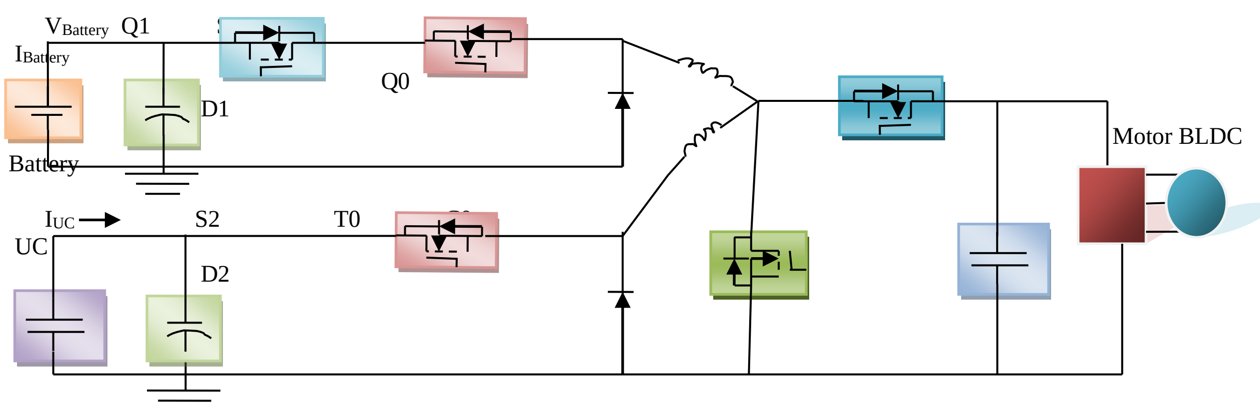

Fig. 2.1 Composition of Multi-input converter for hybrid energy storage system

This MIC operates in three basic modes according to fig.2.2; discharging mode, regenerative mode and charging/discharging mode [13].

2.1 Discharging Mode

In this operating mode, the output fed by input sources according to the states of S1, S2 and T0. Power diodes D1 and D2 operate in a balancing way with switches S1 and S2, correspondingly. In this mode, one switching cycle composed of four subintervals.

ISSN Number: 2454-2024(Online)

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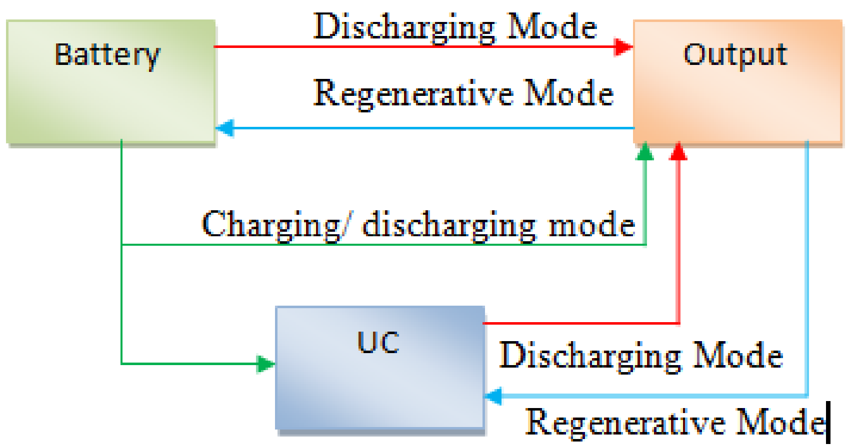

Fig. 2.2 Basic modes of operation of Multi-Input Converter

In this discharging mode, both D1 and D2 in conducting state and both inductor currents decreasing due to turn on the resistance of S0. Furthermore, current in the output capacitor remains negative according to fig. 2.3.

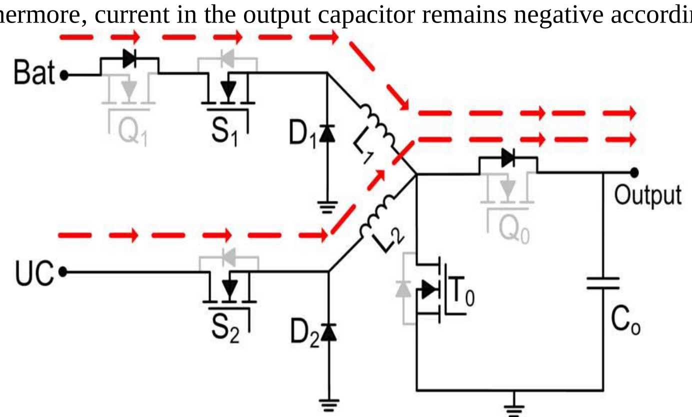

Fig. 2.3 Discharging mode of operation equivalent circuit

The second mode of operation of MIC is the regenerative mode of operation in which regenerative braking energy charges the ESSs by the control of Q0, which depends on the voltage levels of the converter. To control the charging current, a switch Q1 added to the output terminal of the battery. In this regenerative mode, both D1 and D2 are always off and Q0 is off, while the body diode of T0 carries the inductor current according to fig. 2.4.

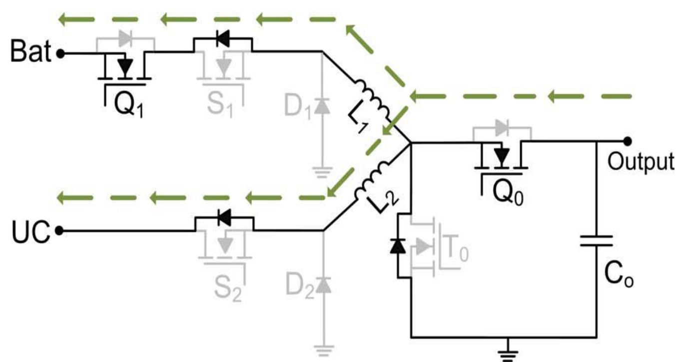

Fig. 2.4 Regenerative mode of operation equivalent circuit

The third mode of MIC is the charging-discharging mode where the mode initiated due to excessive power of one input then the output power. At this time the disused power stored in another input source. The controlling of S1 or S2 done by adjusting the input current according to its reference value; on the other hand, switch T0 controlled to adjust the dc bus. This operating mode explained in fig. 2.5.

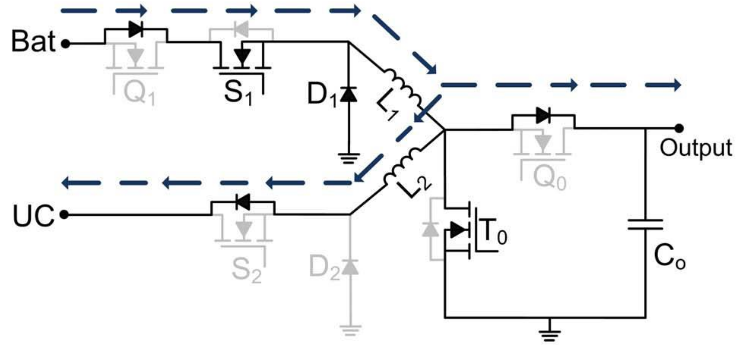

Fig. 2.5 Charging-discharging mode of operation of MIC

Based on these three modes of operation of MIC and their postulations the Q1 is in off condition, only UC charged in the regenerative mode of MIC and the relation between input and output voltages for discharging, regenerative and charging/discharging modes given in equations 15-17 correspondingly.

$$V_0 = V_{battery}\frac{d_{S1}}{1-d_{T0}} = V_{UC}\frac{d_{S2}}{1-d_{T0}}$$

(16)

$$V_0 = V_{battery}\frac{d_{S1}}{1-d_{T0}} = V_{UC}\frac{1}{1-d_{T0}}$$

According to equations, voltages of battery, output and UC in steady-state represented by V_0, $V_{battery}$ and V_{UC}, in that order, while duty cycles denoted by d_{S1}, d_{S2}, d_{T0} and d_{Q0}, correspondingly, and shows the regenerative mode of operation.

Equations found for discharging and charging/discharging mode of operation. For charging/discharging mode d_{S2} becomes1, while body diode of S_2 becomes ON to charge UC.

$$i_{L1}(t) = \frac{1}{L1}\int\left[V_{battery}(t)d_{S1} - V_0(t)(1-d_{T0})\right]dt$$

$$i_{L2} = \frac{1}{L_2}\int[V_{UC}(t)d_{S2} - V_0(t)(1-d_{T0})]dt$$

$$V_0(t) = \frac{1}{C_0}\int[(i_{L1}(t) + i_{L2}(t))(1-d_{T0}) + i_0(t)]dt$$

For the regenerative operating mode of MIC, $i_{L1}(t)$ zero and the output current $i_0(t)$ is negative due to regenerative braking. Voltage and current equations for this operating mode are as:

$$i_{L2}(t) = \frac{1}{L_2}\int\left[V_{UC}(t) - V_0(t)d_{Q0}\right]dt$$

$$V_0(t) = \frac{1}{C_0}\int\left[i_{L2}(t)d_{Q0} + i_0(t)\right]dt$$

3. DESIGN OF A CONTROL STRATEGY

Analysis of converter completion, a suitable control strategy required to design. This control strategy realizes the energy management in the proposed battery-UC HESS smartly. The designed converter and control strategy tested on the proposed HESS according to fig.6. In the figure, the power side represented the proposed converter and the control side represented the raised area for the sensed voltage and current as well as for the control strategy.

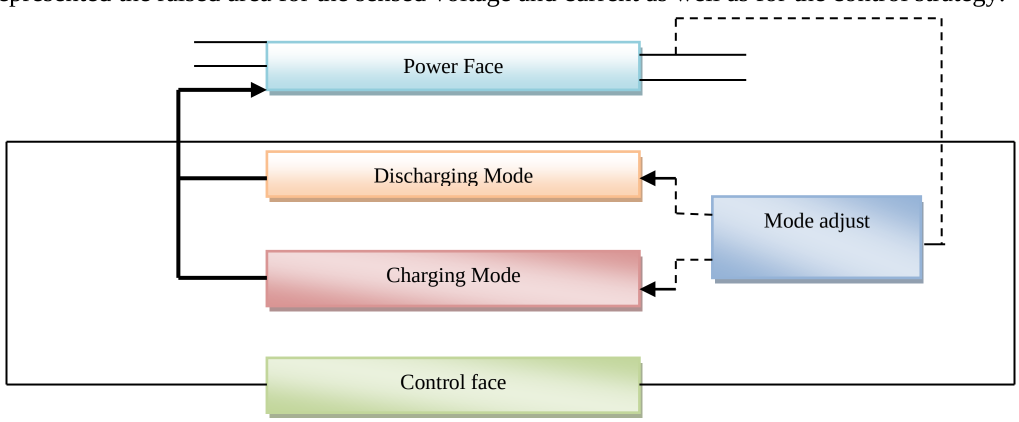

Fig. 3.1 Designed Control Strategy

The Fuzzy Logic Energy Management Strategy determines the operation mode by evaluating the output voltages. These modes are identifying in fig. 3.1, according to this the reference of battery power determined by the FLC (Fuzzy Logic Controller) by taking the output voltage and SOC (State of Charge) of UC into account.

Here, the FLC concluded the battery power to regulate the SOC_{UC} at a reference value. This value determined in a way that UC supply the desired load demand and has adequate capability to detain all the accessible braking energy. To smooth the battery power profile, a rate limiter implemented here to restrict the slew rate of battery power reference and the PI controller adjusted the battery current to attain the desired battery power.

The first mode of operation determined by the checking of output voltage v_o on the control side as when v_o is less than v_o^*- Δ and the battery power $P_{battery}$ less than the output power P_o , the discharging mode activated and when v_o is greater then v_o^*+ Δ, the regenerative mode activated. When the battery power $P_{battery}$ greater than the output power P_o, the charging/discharging mode activated. Where v_o^* represents the output reference voltage and Δ defined the voltage level.

When dT_0 increased, the input voltage range of the converter increased and the impact of this phenomenon is due to increasing the stress on the switches the efficiency decreases. Therefore, the value of dT_0 is set at 0.5 a reasonable value for it in discharging mode. By the regulation of the dc bus, eventually control the power of UC, dS_2 and dT_0 by the use of PI controller.

The main purpose of energy management strategy is that to share the active power between the battery and UC and this can be achieved by the use of a PI (proportional-integral) controller which regulates the duty cycle of S1 to control the battery power and other PI controller maintained the duty cycle of S2 for dc bus regulation. Therefore, the UC power controlled eventually when the battery and UC share the output power demand. To prevent the efficiency reduction of the battery, d_{T0} kept constant at 0.5 in the discharging mode of ESS. On the other hand, for the charging mode of operation, the duty cycle Q_0 regulated by the PI controller to keep the output voltage at its reference value with the T_0 off always.

The FLC having triangular membership functions performs well despite its easy implementation. According to fig.7, the input and output membership functions defined and have two input membership functions SOC_{UC} and P_o (output power).

For SOC_{UC}, there are three input membership functions defined as- Low, Medium and High. For P_o, four input membership functions defined as- Very Low, Low, Medium and High. Additionally the output membership function of $P_{battery}^*$, represented by six output membership functions, which are Very Very Low, Very Low, Low, Medium, High, Very High.

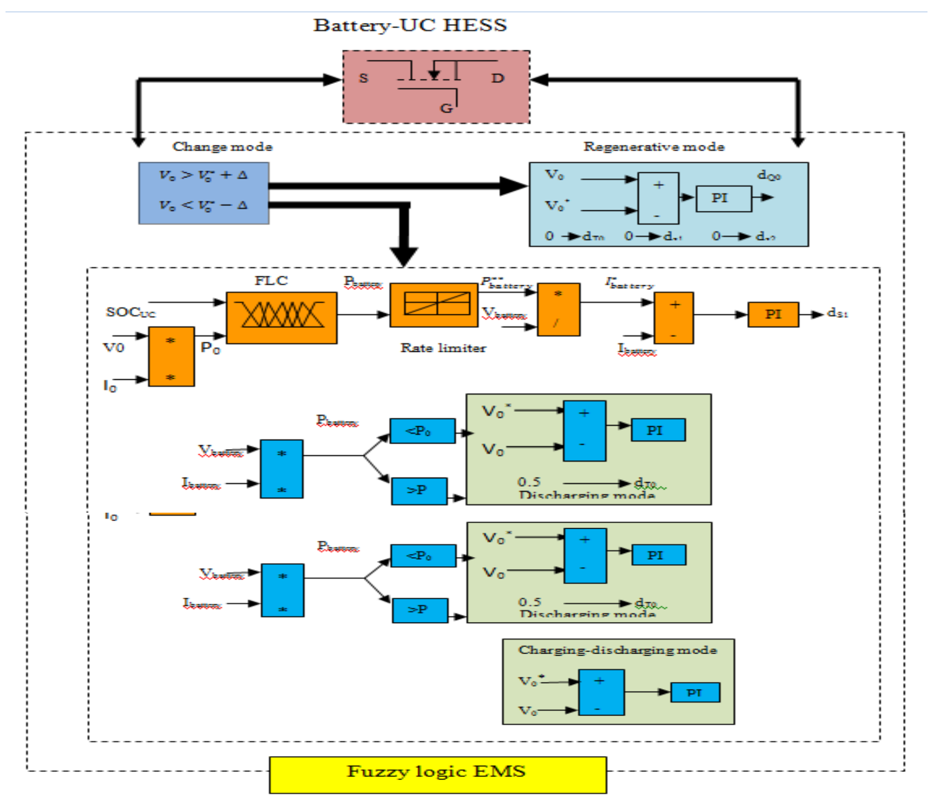

Fig. 3.2 Fuzzy Logic Base Energy Management Control Strategy

ISSN Number: 2454-2024(Online)

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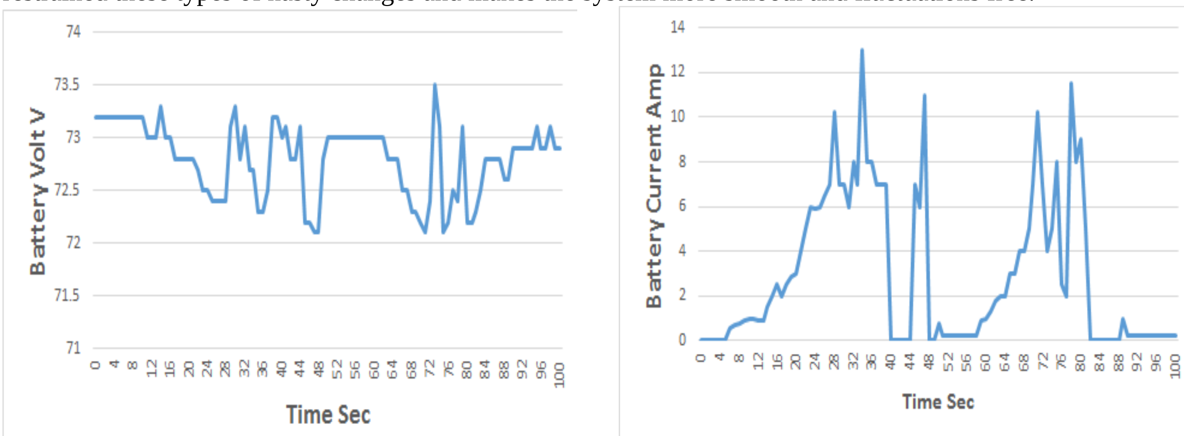
4. RESULTS AND DISCUSSIONS

In Fig. 4.1, the control strategy proved the voltage and current variations for battery ultra capacitor-based the hybrid energy storage system and the result explained about the sudden change in battery current voltage, rate limiter restrained these types of hasty changes and makes the system more smooth and fluctuations free.



(a) (b)

Fig. 4.1 (a) and (b) Experimental results for Battery voltage and current

With the application of Fuzzy based control strategy for power and energy flow between storage systems, the health conditions of the battery as well as ultracapacitor change rapidly. The change showed in Fig.9 clearly and explained the health conditions of storage devices. The planning of control experimentally validated and concluded that the state of charge conditions for ultracapacitor and power output set the reference for battery and according to that, the power of battery profile established. The control management manages the health conditions of ultracapacitor and rate limiter sharpens the results in terms of flicker less or fluctuation free which shown in Fig. 4.2.

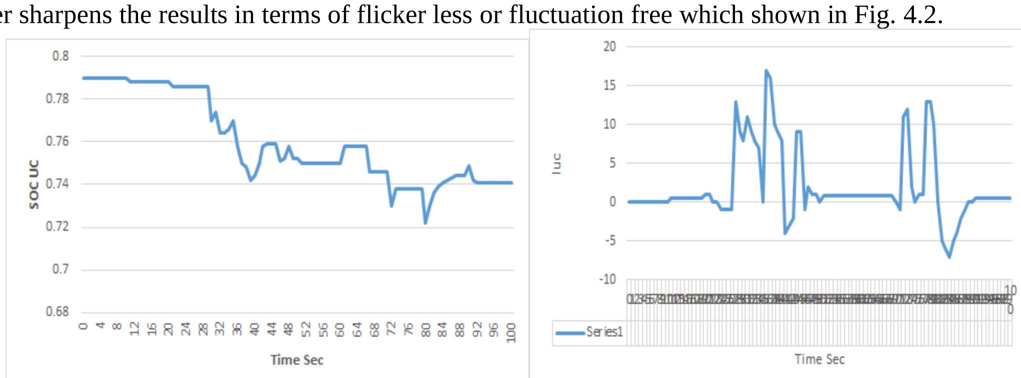


Fig. 4.2 (a) and (b) Experimental results Strategy: SOC and Current of UC

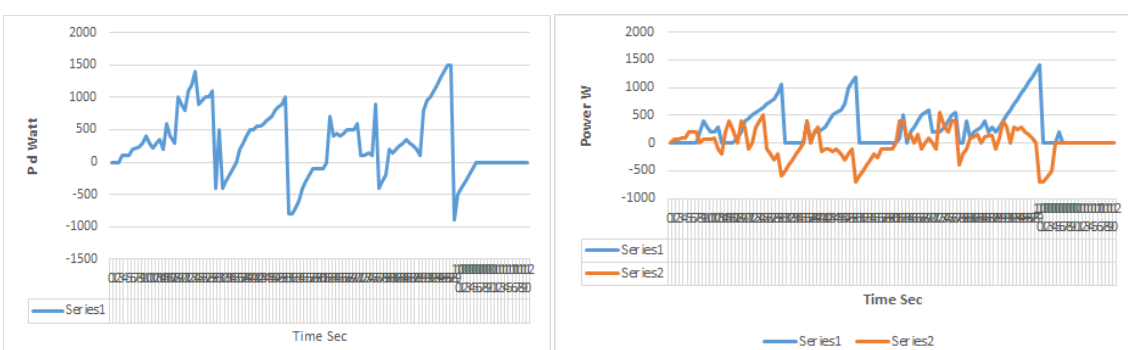


Fig. 4.3 (a) and (b) Experimental results of FLEMS

The three modes of operation of multi-input converter explained in Fig. 4.3, which ejections, regenerative and charging/discharging mode are. In Fig. 4.4, the current and voltage profile of the battery detained that preliminary and ending standard of battery voltage getting minute because of high-energy concentration of battery storage. With the managed and implemented control theory, the charging conditions and standards profile get effective and efficient.

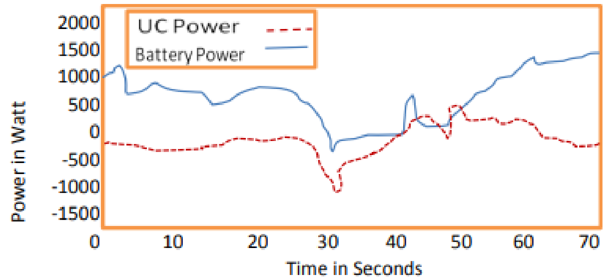
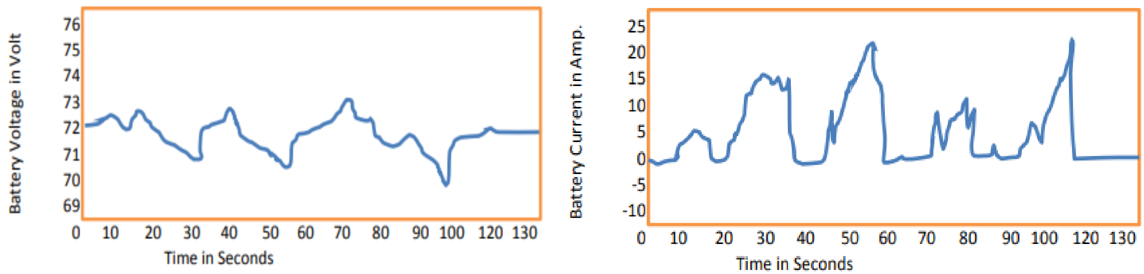
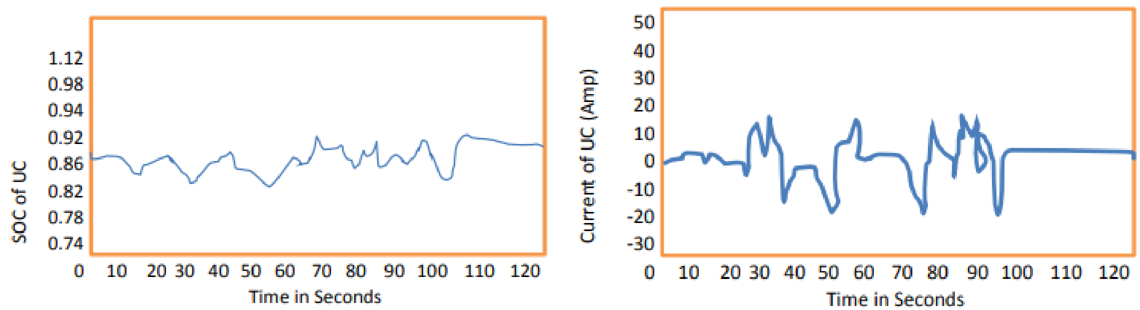


Fig. 4.4 Experimental Results of Strategy for mode changeover



a. b.

Fig. 4.5 (a) and (b) Experimental results for control strategy for Battery Voltage and Current



a. b.

Fig. 4.6 (a) and (b), Tentative Results of Energy management Strategy: Voltage and Current of UC

CONCLUSION

The theory of management of control approach based on Fuzzy Logic explained the battery behaviour regarding power profile and health conditions. The results achieved by the implementation of control strategy much better than other conventional approaches. The theory expected to enhance the battery profile and life cycle by the suppression of power crests as well as the research approach made the storage system more efficient and made available for use in systems. The approach validated experimentally and then evaluated and compared with other conventional control approaches. The consequences of the approach improve the life cycle of battery about 60% than previous used battery and storage systems. The methodology made the storage system efficient with better health conditions of storage elements like battery and ultracapacitor also guaranteed the possibility of the hybrid system with the consideration of describe input voltage range of the converter.

REFERENCES

[1] Furkan Akar, Yakup Tavlasoglu, and Bulent Vural, “An Energy Management Strategy for a Concept Battery/Ultracapacitor Electric Vehicle with Improved Battery Life”, IEEE TRANSACTIONS ON TRANSPORTATION ELECTRIFICATION, VOL. 3, NO. 1, MARCH 2017.

[2] Li Tang, Giorgio Rizzoni and Simona Onori, “Energy Management Strategy for HEVs Including Battery Life Optimization”, IEEE TRANSACTIONS ON TRANSPORTATION ELECTRIFICATION, VOL. 1, NO. 3, OCTOBER 2015.

[3] Oleg Gomozov, João P. Trovão, Xavier Kestelyn, R. Dubois, “Adaptive Energy Management System Based on a Real-Time Model Predictive Control with Non-Uniform Sampling Time for Multiple Energy Storage Electric Vehicle”, IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY.

[4] Junyi Shen and Alireza Khaligh, "Predictive Control of a Battery/Ultracapacitor Hybrid Energy Storage System in Electric Vehicles", 978-1-5090-0403-4/16/$31.00 ©2016 IEEE.

[5] Yuping Zhang, Yi Mou and Zhongxiao Yang, "An Energy Management Study on Hybrid Power of Electric Vehicle Based on Aluminum Air Fuel Cell ", 10.1109/TASC.2016.2610719, IEEE Transactions on Applied Superconductivity.

[6] T. Mesbahi, N. Rizoug, P. Bartholomeüs, R.Sadoun , F.Khenfri, P. LeMoigne, "Optimal Energy Management For a Li-Ion Battery/Supercapacitor Hybrid Energy Storage System Based on Particle Swarm Optimization Incorporating Nelder-Mead Simplex Approach", 10.1109/TIV.2017.2720464, IEEE Transactions on Intelligent Vehicles.

[7] Haoran Fang, Naxin Cui, Feng Wang, Chenghui Zhang, "Lithium-ion Battery Charging Strategy for Electric Vehicles Based on Particle Swarm Optimization Method", 978-1-5386-7/17/ ©2017 IEEE.

[8] Li Sun, Kaiwu Feng, Chris Chapman and Nong Zhang, "An Adaptive Power-Split Strategy for Battery–Supercapacitor Powertrain—Design, Simulation, and Experiment", IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 32, NO. 12, DECEMBER 2017.

[9] Khaled Alobeidli and Vinod Khadkikar, "A New Ultracapacitor State of Charge Control Concept to Enhance Battery Lifespan of Dual Storage Electric Vehicles", 10.1109/TVT.2018.2871038, IEEE Transactions on Vehicular Technology. Vaishakh.M.Nayanar and Ms.Keerti.S.Nair 2019, "Fuzzy & PI Controller Based Energy Management Strategy of Battery/ Ultracapacitor For Electric Vehicle", 2019 2nd International Conference on Intelligent Computing, Instrumentation and Control Technologies (ICICICT), 978-1-7281-0283-2/19/$31.00 ©2019 IEEE.

[10] Zhenhua Cai, Beigao Chen, Chengxin Luo, Huijuan Lian, "A Fuzzy control based energy management strategy for LFP/UC hybrid electric vehicular energy system", 978-1-5386-2/17/©2017 IEEE.

[11] M. Ehsani, Y.M. Gao, A. Emadi, "Modern electric, hybrid electric, and fuel cell vehicles," CRC press, Boca Raton, 2010.

[12] L. Tang, G. Rizzoni, S. Onori, "Energy Management Strategy for HEVs Including Battery Life Optimization," IEEE Transactions on Transportation Electrification, vol. 1, no. 3, 2015

[13] C. Zheng, G. Xu, S. W. Cha, and Q. Liang, "A predictive driving control strategy of electric vehicles for energy saving," Int. J. Precis. Eng. Manuf., vol. 16, no. 1, pp. 197–202, 2015.

[14] B. Hredzak, V. G. Agelidis, and M. Jang, "A model predictive control system for a hybrid battery-ultracapacitor power source," IEEE Trans. Power Electron., vol. 29, no. 3, pp. 1469–1479, Mar. 2014.

[15] M. C. Kisacikoglu, M. Uzunoglu, and M. S. Alam, "Fuzzy logic control of a fuel cell/battery/ultra-capacitor hybrid vehicular power system," in Proc. IEEE Vehicle Power Propuls. Conf. (VPPC), Sep. 2007, pp. 591–596.

[16] A. A. Ferreira, J. A. Pomilio, G. Spiazzi, and L. de Araujo Silva, "Energy management fuzzy logic supervisory for electric vehicle power supplies system," IEEE Trans. Power Electron., vol. 23, no. 1, pp. 107–115, Jan. 2008.

[17] J. Kim and B.-H. Cho, "State-of-charge estimation and state-of-health prediction of a li-ion degraded battery based on an EKF combined with a per-unit system," IEEE Trans. Veh. Technol., vol. 60, no. 9, pp. 4249–4260, Nov. 2011.

[18] M. Ansarey, M.S. Panahi, H. Ziarati, M. Mahjoob, "Optimal energy management in a dual-storage fuel-cell hybrid vehicle using multi-dimensional dynamic programming," J. Power Sources, vol. 250, pp. 359-371, 2014.

[19] L. Tang, G. Rizzoni, S. Onori, "Energy Management Strategy for HEVs Including Battery Life Optimization," IEEE Transactions on Transportation Electrification, vol. 1, no. 3, 2015.

[20] X. Zeng and J. Wang, "A parallel hybrid electric vehicle energy management strategy using stochastic model predictive control with road grade preview," IEEE Trans. Control Syst. Technol., vol. 23, no. 6, pp. 2416–2423, Nov. 2015.

[21] F. Akar, Y. Tavlasoglu, E. Ugur, B. Vural, and I. Aksoy, "A bidirectional nonisolated multi-input DC–DC converter for hybrid energy storage systems in electric vehicles," IEEE Trans. Veh. Technol., vol. 65, no. 10, pp. 7944–7955, Oct. 2016.

[22] F. Akar and B. Vural, "Battery/UC hybridization for electric vehicles via a novel double input DC/DC power converter," in Proc. 3rd Int. Conf. Electr. Power Energy Convers. Syst. (EPECS), Oct. 2013, pp. 1–4.

[23] [24] O. Erdinc, B. Vural, M. Uzunoglu, and Y. Ates, "Modeling and analysis of an FC/UC hybrid vehicular power system using a wavelet-fuzzy logic based load sharing and control algorithm," Int. J. Hydrogen Energy, vol. 34, no. 12, pp. 5223–5233, Jun. 2009.