Control strategy for battery life enrichment in Hybrid Energy Storage System for Electric Vehicles

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Abstract: The theory of energy management strategy (EMS) presented in the paper, which implemented on the battery-Ultra capacitor (UC) based hybrid energy storage system for electrical vehicles. The paper realizes the better performance of a hybrid energy storage system (HESS) with the combo of the attributes of the battery-ultra capacitor, with the landform information, which assured the system for continuous hybridization for the period of drive cycle of EV. The correlated EMS is the main goal of the research for prolonging the battery life and enhances the survival of electric vehicle. The fuzzy control based EMS and a real-time based strategy provide the accurate control of energy sharing between battery-UC. The fuzzy logic control developed with the combination of model prediction and rule-based management system of the energy. The concept of theory validated through MATLAB/SIMULINK with three patterns of driving specifically with various speed patterns 45-50 Km/h, 50-60 Km/h and 60-70 Km/h. The outcomes of the control strategy evaluated in terms of utilization of energy between battery-UC for the Electric vehicle. The outcomes of an optimized adaptive rule-based controller ensured that the hybrid energy storage system capable of functioning steadily and provide a wide range of drive cycles.

Key Factors: Hybrid energy storage system (HESS), Energy Management Strategy (EMS), Electric Vehicles (EVs) and adaptive controllers.

1. Introduction

Automotive Sector faced the worldwide sustainability of energy and environmental issues and for the last few decades, Electric vehicles playing a very important job in making solution to related problems. The researchers conducted various researches for the motivation towards the renewable energy resources as a replacement of consumption of fossil fuels. The two major aspects considered by the researchers one is the risk or danger of global warming and another is the exhaustion of petroleum basins in the world. According to these concerned aspects required to decrease the air contamination and hazardous secretion from the conventional vehicles as well as they encouraged the progression of EVs. These EVs powered and relocated by HESS and this HESS can acquire from end to end a fruitful amalgamation of two or more energy storage devices [1]-[3]. The amalgamation of battery with the ultracapacitor (UC) resolved the precise low energy of UC and definite low battery power [4]. HESS is a perfect realistic resolution, which employed in EV purpose [5][6]. The major storage device for HESS is the battery which supplies the steady load with high energy density and UC applied as a supplementary device for storage with a high power density and provide a fast energetic reaction for the modified power for the load [8]-[9]. The research also included a HESS for EV consists of battery-UC combination for energy storage [10]. The major portion of energy storage by the battery with superior capacity to hold the higher energy density and UC have a high density of power rather than the energy with the help of bidirectional DC-DC converter technologies. Abundant learning journalism endeavors the proposed battery-UC combination of HESS for EVs [11]. The research study shows the various topologies of the bidirectional DC-DC converters for the applications in EVs for the configuration of HESS according to fig.1. According to fig.1 (ii), the most favorable topology prescribed in the semi-active HESS with the bidirectional DC-DC converter to limits the flow of power from UC to DC bus and maintain the healthier conditions of the system.

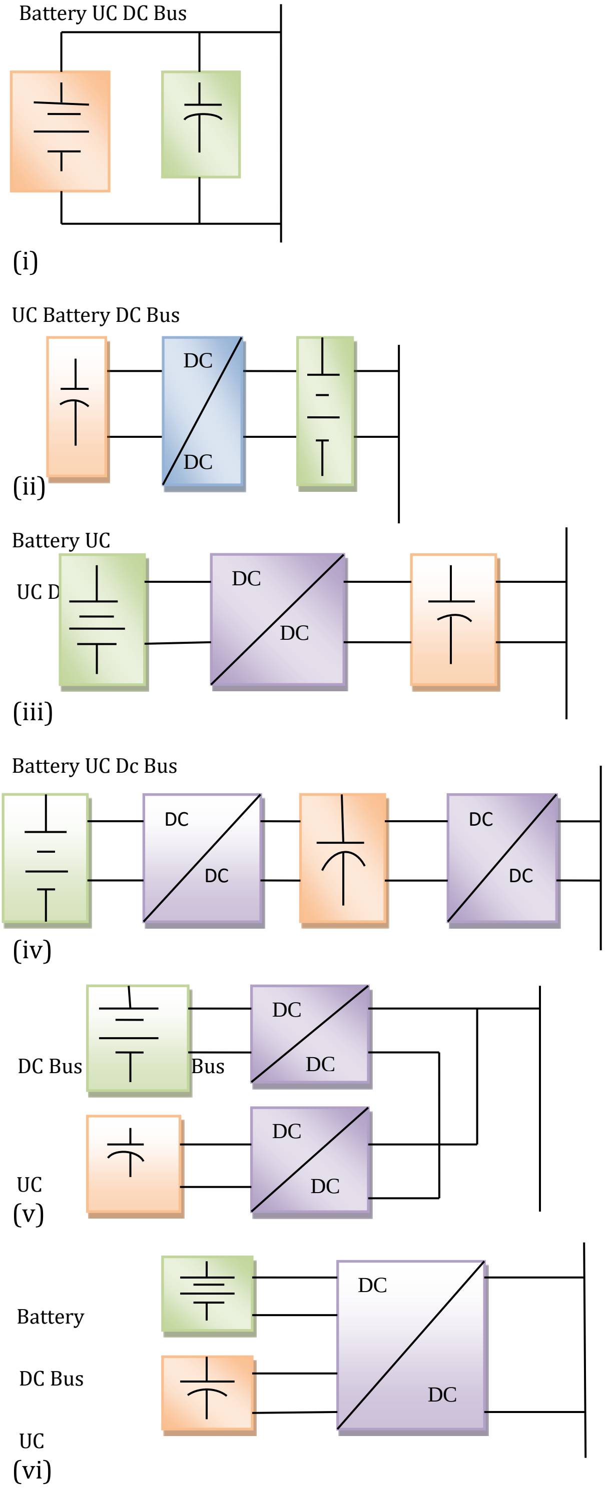


Fig. 1(i), (ii), (iii), (iv), (v), (vi) Common HESS structural design

The EMS applied for an arrangement of the partially active technique for hybrid energy storage system and manages or controls the power flow between the battery and UC for a hybrid energy storage system with the account of regenerative energy for the vehicle [17]. The controller based on fuzzy rule sets applied between UC and battery, which distributes flow of load and result from the adopted controller, exaggerated the sharing of power between the battery and UC [18]. The fuzzy logic-based control strategy used to distribute and examined the power sharing between UC and battery [19]. The neural network and model predictive control based strategies distinguish as on the spot procedure for optimization, and performance of these controllers compared with the active programming with minimum operational cost. Whereas the neural network required the number of samples for the data predicted for the training of controller as well as the class of sampled data which highly affected by the predicted precise accuracy for the system [20]. The most prominent advantage of the hybrid energy storage system is to enhance the life of the battery due to suppressing the peak spike of battery current. Furthermore, the validated results expressed the increased life cycle of a pack of battery with the help of Ultracapacitor [21]. In Energy management strategy classified in two forms online and offline, in online strategies the rule-based control, model predictive control strategy, based on filtration technique, corresponding utilization based minimization strategy and so on. As compared with on and offline strategies, the off lines are easier to implement but practically very difficult for the implementation purpose. Another control mechanism designed and implemented for the distribution of power between the battery and UC achieved the efficiency of the hybrid energy storage system as well as the enhanced life cycle of the complete battery system [22]. The theory of designed controllers based constructed rule base and fuzzy adaptive rule base also the results of theory told about the enhancement of the life of the battery. The major approach for fabrication of controller to distribute the power of load among the battery and UC, the controller also normalize the DC bus voltage and supervise the state of charge of the UC. The research results examined the controller behavior for the property of life enhancement of battery with the continuous supply of load energy from the battery and as well as from the ultracapacitor when transients occurred in that. The semi-active hybrid energy storage system for the application of electric vehicles examined the research work with the control algorithms. These algorithms use to divide the required current optimally for the vehicle between the battery and UC for the enhanced life of the battery and hybridization of the energy storage system. In this concept of hybridization, the battery offers a low current for traction and exhausts the regenerated current during the braking of the vehicle.

2. System Architecture of Hybrid Energy Storage System for Electric Vehicle

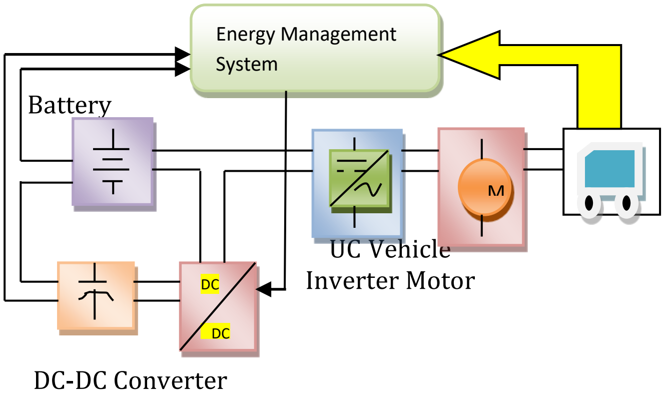


Fig.2 HESS architecture for EVs

According to fig.2, the topology for the converter based on the semi-active topology for the hybrid energy storage system used in an electric vehicle. The designed controller used in the system to distribute the power and energy which maintained the balance between demand power and battery current as well as peak demand of current and exhausted energy during regenerative braking. The designed rule-based controller arranges for the flow of power from the ultracapacitor and the amendment in the drive cycle for the DC-DC converter shown in the architecture of the electric vehicle.

i. MODELING OF BATTERY

The equivalent circuit model for the battery results in the deeply researched on the battery behavior and one of the models used with the features of runtime based, impedance model. With the use of the parameter estimation approach, various researchers recognized the factor values of the equivalent circuit model for batteries. Equation (1) tells the entrenched model of the battery and the relationship between its parameters in the MATLAB/Simulink library. The related theory represents the health conditions of battery in terms of the state of charge (SOC) in equation (1), the major parameters used for the research work, shown in table 1.

TABLE 1. Required Constraints for Battery Model

S.No.	constraint	significance
1	Internal Resistance (Ohms)	0.125 ohms
2	Capacity (Ah)	110
3	Nominal Voltage (Volt)	525
4	Stored Energy (kWh)	52

$$V_{battery}(t) = E_{battery}(t) - r_{battery}.i_{battery}(t)$$

$$SOC_{(time)} = 100\left(SOC(0) - \frac{1}{Q}\int_{0}^{t} i_{(t)}dt\right) \quad (1)$$

ii. SUPERCAPACITOR MODEL

The UC model invented in various studies or researches for the enhancement of activeness and high strength of the energy storage devices for energy management strategy and mathematical modeling. The UC model has shown an equivalent circuit and terminal measurement for charging and discharging. The parameters used for UC modeling according to table 2 and the terminal voltage V_{UC} and total capacity C_{UC} computed according to equation 2.

$$C_{UC} = \frac{C_{Cell} \, . \, N_{parallel}}{N_{series}}$$

$$V_{UC} = V_{cell} . N_{series} \text{ (2) (2)}$$

Table 2: UC modal's parameters

S.No.	constraint	significance
1	Resistance (m-Ohm)	2.2
2	Rated voltage (volt)	310
3	Rated capacitance (Farad)	110

iii. DC-DC CONVERTER MODEL

The DC-DC converter modeling shows the linear and non-linear performances of the energy storage system with the help of a state-space model. The recognized techniques further simplified the converter model and lesser the time of simulation for the converter system. In equation (3) the ON-OFF state matrices derived for the converter.

$X = [I_l \; V_c]T \equiv$ State Vector (3)

3. CONTROL STRATEGY FOR ENERGY MANAGEMENT IN HESS

For the distribution of the total current of an electric vehicle between battery and UC of the hybrid energy storage system, an adaptive rule-based controller examined and after that implemented on it. $I_{converter}$, The output current of DC-DC converter prohibited by the adaptive rule-based controller and maintained the output of the energy for the UC. In equation (4), the total load current of vehicle I_{total} described and calculated with the help of this equation.

$$I_{total}(t) = I_{battery}(t) + I_{converter}(t) \text{ (4)}$$

The rule-based controller distributed the current between the battery and UC and controlled the battery current $I_{battery}$ in a desired limited range $I_{battery\ maximum}$. The control strategy maintains the flow of energy according to different constraints as total demand of load current I_{total}, the direction of the flow of energy, state of charge conditions of UC. According to controller theory, when the total load current of an electric vehicle lesser than the maximum current value for the battery $I_{battery\ maximum}$ the controller allows the current to the electric vehicle from the HESS as well as it limits or prohibits the current from the controller during heavy load of driving cycle. The theory of controller explained into two parts, one from rule-based which divides the energy between battery and UC and another one is adaptive fuzzy rule-based controller with the uses of fuzzy logics and these two forms determines the energy saving in controllers during various driving cycles.

I RULE BASED ADAPTIVE CONTROLLER

The adaptive rule base controller performed the task of energy sharing between battery and UC in the hybridized energy storage system. The controller performed an estimation of the total required energy during the drive cycle of the vehicle. Based on the current accumulation method for supplied positive current $I_{positive}$ and regenerative current $I_{regenerative}$, the total current has been distinct in equation (5).

$$I_{regenerative} = \sum_{0}^{t} I_{total}\ (t)\ I_{total} < 0$$

$$I_{positive} = \sum_{0}^{t} I_{total}\ (t)\ I_{total} > 0 \text{ (5)}$$

The implementation of the controller suppresses the pressure on the battery and saved the energy of the hybrid energy storage system. This technique shows the proper functioning of HESS with the help of power distribution calculation between the UC and battery and UC absorb the completely regenerative energy during the driving of a vehicle.

II ADAPTIVE FUZZY RULE-BASE CONTROLLER

The fuzzy adaptive controller based control strategy for energy management used to maintain the distribution of power between the battery and UC. The basic constraints of the controller increase the efficiency of the system at the highest approach also deduces the fluctuations in the current of the battery as well as decreases the state of charging of UC. The designed whole strategy based on three main concepts; the first one is the necessary conditions for driving cycles should steadily gather. Second, the health conditioning for battery and battery dynamics and the third one is the real or actual resources of energy levels of an electric vehicle. Fig.3 shows the three concepts of designed strategy.

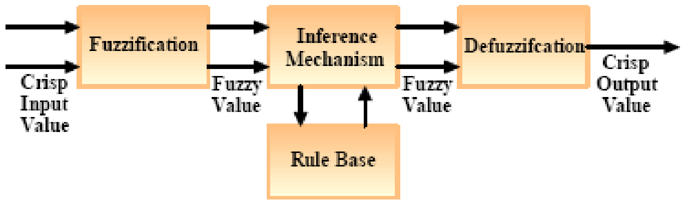
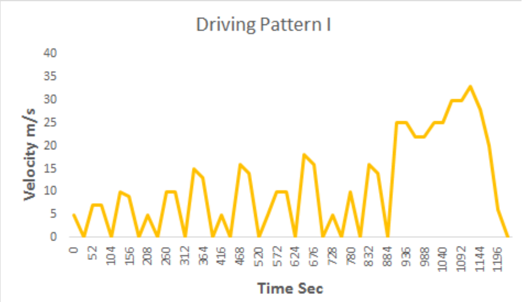
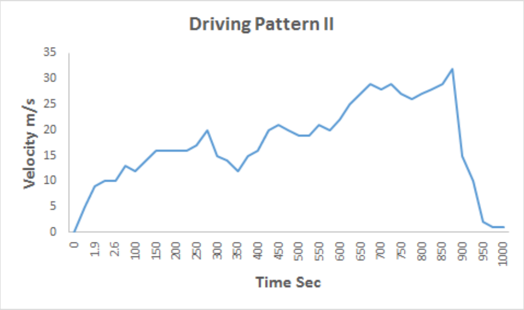


Fig. 3 Adaptive Fuzzy Logic Controller for Energy Management Strategy

4. Outcomes and Conversation

After validated the presence of the partially active HESS and examined the tentative outcomes with three driving patterns for vehicle drive which shown in fig.5. The major attributes of the driving pattern explained in table 3 and major attributes for the vehicle described here.





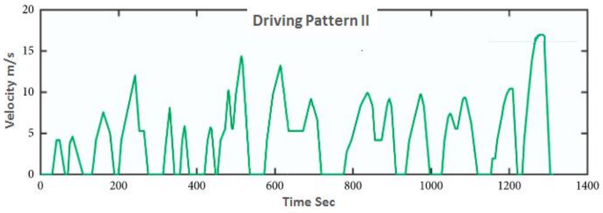


Fig. 5 Three driving patterns for electric vehicle

Table 3 Major attributes of the driving ranges

Constraints	**Driving pattern 1 for Uphill**	**Driving pattern 2 for down hill**	**Driving pattern 3 for City trip**
inactive time sec.	300	6.8	287
Maximum velocity m/s	34.	28.22	18.23
Average velocity m/s	10.11	23.44	7.2
Maximum acceleration m/s^2	1.09	2.2	2.1
Average acceleration m/s^2	1.22	0.2	0.33
Maximum deceleration m/s^2	-1.45	-1.5	-2.4
Average deceleration m/s^2	-0.8	-0.3	-0.397

For the first driving pattern, which is the 40-50 Km/h range, the hybrid energy storage system absorbed 1.47% of energy from the battery stored in that with the use of an adaptive rule base controller whereas UC absorbed 11.22% from the total energy stored. When applied all these data for the required driving pattern on fuzzy adaptive rule base controller, the HESS absorbed 1.1% of the total energy stored in the battery and 20.11% absorbed from the ultracapacitor. Fig.6 (a) shows the health conditions for the battery with the representation of the state of charge conditions. Fig.6 (b) shows the state of charge conditions for the ultra capacitor under the uphill driving conditions.

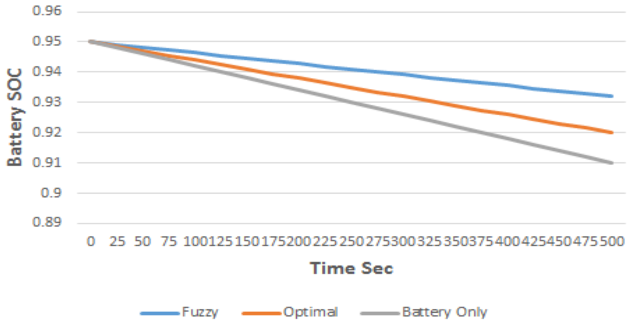


Fig.6 (a) State of charge conditions of battery for driving pattern for Uphill

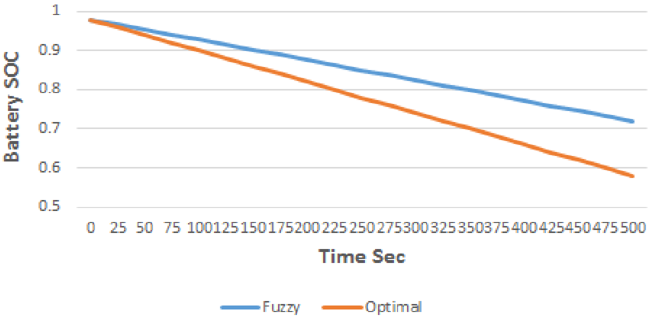
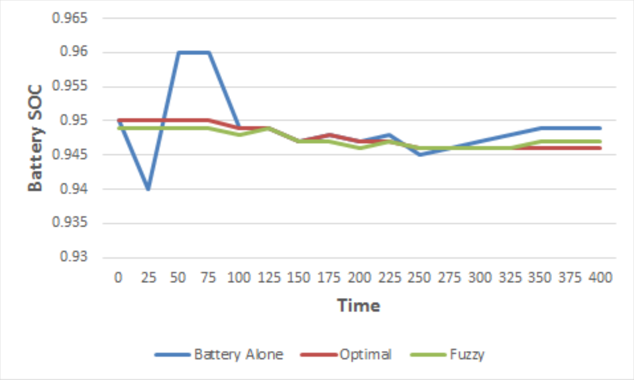


Fig.6 (b) State of charge conditions of Ultra capacitor for driving pattern for Uphill



6 (c) State of charge conditions of battery for driving pattern for downhill

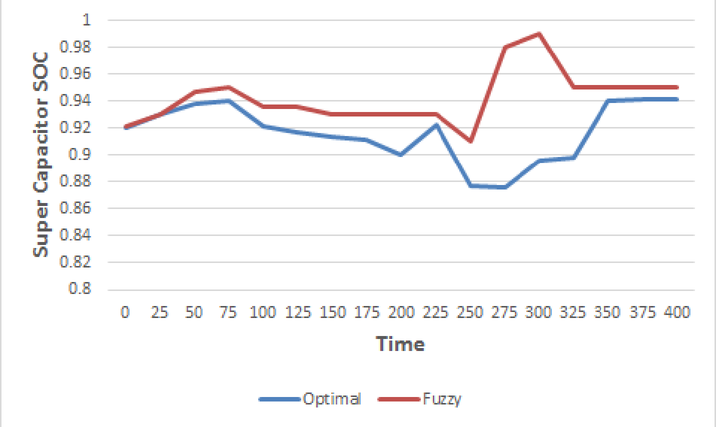


Fig.6 (d) State of charge conditions of Ultracapacitor driving pattern for downhill

The outcomes from fig.6 (b) explained that with the double energy sources, battery health conditions remain much better as compared to the single energy source. Fig. 6 (c) and (d) explained the variation during the downhill driving. The experimental outcomes for the fuzzy rule base controller show the enhancement in battery profile in terms of low energy losses and efficient operating conditions. In fig. 7 (a) and 7 (b) examined the state of charging conditions for battery and UC for the HESS in an electric vehicle with different driving patterns and concluded that the fuzzy rule base controller efficiently worked on the energy storage devices regarding the charging conditions, efficient working and as well as energy absorption during the driving of vehicles.

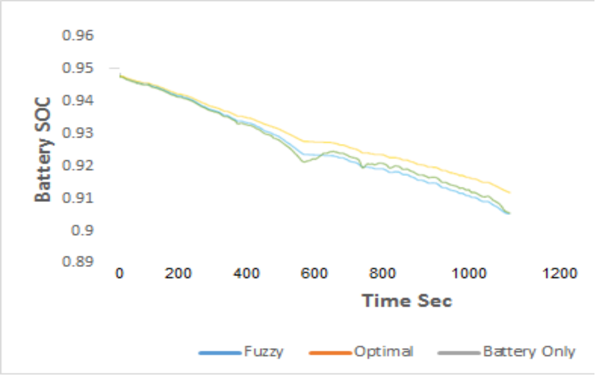
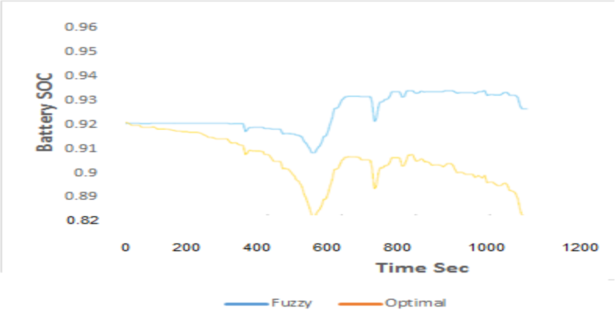


Fig. 7 (a) Battery state of charge conditions for HESS



7 (b) UC state of charge conditions for HESS

5. CONCLUSION AND SUMMARY

The summary concluded that the fuzzy rule base strategy for control of battery-UC based hybrid energy storage devices in EVs, which validated on three driving conditions. The proposed controllers proved the significance of the operation of electric vehicle on different driving patterns with efficient charging conditions, maintained health conditions of battery and UC with state of charge conditions. The controllers enhances the battery life cycle by suppressing pressure on current during heavy load conditions of the vehicle and makes the HESS effective and efficient for EVs. In addition, the theory of control strategy concluded that the voltage dive in battery compacted in the range of 36-37.5% range and 32.22% as compared with the single battery system in three various driving patterns. The current inside the bundle of battery compacted within the range of 29.23% and 53.43%, as compared with the single battery storage system. Therefore, this theory is the efforts for the combination of some various advancements in the control strategy for energy management to cancel out the shortcoming of energy management techniques such as Neural Network or optimization, which are in the previous or early phase of improvement.

REFERENCES

[1] E. Schaltz, Electrical Vehicle Design and Modeling. London, U.K.:INTECH Open Access, 2011.
[2] S. Manzetti and F. Mariasiu, ―Electric vehicle battery technologies: from present state to future systems,‖ Renew. Sustain. Energy Reviews, vol. 51, pp. 1004-1012, November 2015.
[3] L. Kouchachvili, W. Yaïci and E. Entchev, ―Hybrid battery/supercapacitor energy storage system for the electric vehicles,‖ J. Power Sources, vol. 374, pp. 237-248, January 2018.
[4] V. Paladini, T. Donateo, A. de Risi, and D. Laforgia, ``Super-capacitors fuel-cell hybrid electric vehicle optimization and control strategy development,'' Energy Convers. Manage., vol. 48, no. 11, pp. 3001_3008, Nov. 2007.
[5] Y. Li, X. Huang, D. Liu, M. Wang, and J. Xu, ``Hybrid energy storage system and energy distribution strategy for four-wheel independent-drive electric vehicles,'' J. Cleaner Prod., vol. 220, pp. 756_770, May 2019.
[6] O. Veneri, C. Capasso, and S. Patalano, ``Experimental investigation into the effectiveness of a super-capacitor based hybrid energy storage system for urban commercial vehicles,'' Appl. Energy, vol. 227, pp. 312_323, Oct. 2018.
[7] C. Capasso, D. Lauria, and O. Veneri, ``Experimental evaluation of modelbased control strategies of sodium-nickel chloride battery plus supercapacitor hybrid storage systems for urban electric vehicles,'' Appl. Energy, vol. 228, pp. 2478_2489, Oct. 2018.
[8] P. Mellor, N. Scho_eld, and D. Howe, ``Flywheel and supercapacitor peak power buffer technologies,'' in Proc. Electr., Hybrid Fuel Cell Vehicles, 2000, pp. 8-1_8-5.

[9] Y. Zhang, Z. Jiang, and X. Yu, ``Control strategies for battery/supercapacitor hybrid energy storage systems,'' in Proc. Energy Conf., 2008, pp. 1_6.
[10] F. Ju, Q. Zhang, W. Deng, and J. Li, ``Review of structures and control of battery-supercapacitor hybrid energy storage system for electric vehicles,'' in Proc. IEEE Int. Conf. Autom. Sci. Eng. (CASE), Taipei, Taiwan, Aug. 2014, pp. 143_148.
[11] S. F. Tie and C. W. Tan, ``A review of energy sources and energy management system in electric vehicles,'' Renew. Sustain. Energy Rev., vol. 20, pp. 82_102, Apr. 2013.
[12] J. Cao and A. Emadi, ``AnewBattery/UltraCapacitor hybrid energy storage system for electric, hybrid, and plug-in hybrid electric vehicles,'' IEEE Trans. Power Electron., vol. 27, no. 1, pp. 122_132, Jan. 2012.
[13] C. Xiang, Y. Wang, S. Hu, and W. Wang, ``A new topology and control strategy for a hybrid battery-ultracapacitor energy storage system,'' Energies, vol. 7, no. 5, pp. 2874_2896, Apr. 2014.
[14] A. Ostadi, M. Kazerani, and S.-K. Chen, ``Hybrid energy storage system (HESS) in vehicular applications:Areviewon interfacing battery and ultra capacitor units,'' in Proc. IEEE Transp. Electri_c. Conf. Expo (ITEC), Jun. 2013, pp. 1_7.
[15] S. Du, Key technologies research on energy management of pure electric vehicle with dual-energy storage system [D]. Jilin University, 2015.
[16] M. Michalczuk, B. Ufnalski, and L. M. Grzesiak, ``Fuzzy logic based power management strategy using topographic data for an electric vehicle with a battery-ultracapacitor energy storage,'' Int. J. Comput. Math. Electr. Electron. Eng., vol. 34, no. 1, pp. 173_188, Jan. 2015.
[17] W. Han, Y. Li, and L. Chen, ``High-precision DEM production in complex urban area using LiDAR data,'' in Proc. 20th Int. Conf. Geoinformatics, Jun. 2012, pp. 1_5.
[18] Q. Zhang andW. Deng, ``An adaptive energy management system for electric vehicles based on driving cycle identi_cation and wavelet transform,'' Energies, vol. 9, no. 5, p. 341, May 2016.
[19] J. Shen and A. Khaligh, ``Design and real-time controller implementation for a battery-ultracapacitor hybrid energy storage system,'' IEEE Trans. Ind. Informat., vol. 12, no. 5, pp. 1910_1918, Oct. 2016.
[20] K. V. S. Bharath and K. Pandey, ``Fuzzy-based multi-objective optimization for subjection and diagnosis of hybrid energy storage system of an electric vehicle,'' in Proc. Int. Conf. Intell. Commun., Control Devices, 2017, pp. 299_307.
[21] A. Castaings, A. Bouscayrol, R. Trigui, and W. Lhomme, ``Practical control schemes of a battery/supercapacitor system for electric vehicle,'' IET Electr. Syst. Transp., vol. 6, no. 1, pp. 20_26, Mar. 2016.
[22] Z. Song, J. Li, J. Hou, H. Hofmann, M. Ouyang, and J. Du, “The battery-supercapacitor hybrid energy storage system in electric vehicle applications: A case study,” Energy, vol. 154, pp. 433–441, 2018.