Power Management Of Solar Based DCMG Supported By Hybrid Energy Storage System

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Abstract- *The integration of renewable energy sources, particularly solar power, into the grid has gained significant attention due to its environmental benefits and potential to address energy demands. However, the intermittent nature of solar power necessitates efficient energy storage solutions to ensure a reliable and sustainable power supply. This paper investigates the power management strategies for a Direct Current Microgrid (DCMG) powered by solar energy and supported by a Hybrid Energy Storage System (HESS). The HESS comprises batteries and supercapacitors, each with distinct characteristics and advantages. The proposed power management system aims to optimize the utilization of solar energy, minimize energy losses, and ensure the stability of the DCMG. The system employs a combination of advanced control techniques, including model predictive control (MPC) and rule-based strategies, to coordinate the energy flow between the solar source, HESS, and load. Through simulations and experimental validation, the effectiveness of the proposed system in improving the overall performance of the solar-powered DCMG is demonstrated.*

Keywords*- BEV (Battery Electric Vehicle), ESS (Energy Storage Scheme), SOC (State Of Charge), PMSM(Permanent Magnet Synchronous Motor) etc.*

I. INTRODUCTION

The increasing global concern regarding climate change and energy security has led to a surge in the adoption of renewable energy sources. Among these, solar energy has emerged as a promising solution due to its abundance and environmental friendliness. However, the intermittent nature of solar power, characterized by fluctuations in solar irradiance, poses challenges in maintaining a reliable and stable power supply. To address this issue, energy storage systems (ESS) have been integrated with renewable energy systems to store excess energy during periods of high generation and release it during periods of low or no generation.

Hybrid Energy Storage Systems (HESS), which combine multiple storage technologies, have gained significant attention due to their ability to leverage the advantages of different storage devices. By combining batteries and supercapacitors, HESS can provide both high energy density and high power density, enabling efficient energy storage and delivery.

Direct Current Microgrids (DCMGs) offer several advantages over traditional AC microgrids, including reduced power losses, improved power quality, and increased efficiency. However, the successful operation of DCMGs requires effective power management strategies to optimize energy utilization and ensure system stability.

This paper focuses on the development and implementation of a power management system for a solar-powered DCMG supported by a HESS. The proposed system aims to:

1.   Maximize solar energy utilization: Efficiently utilize the available solar energy to meet the load demand and charge the HESS.

2.   Optimize energy storage: Coordinate the charging and discharging of the battery and supercapacitor to prolong their lifespan and improve overall system performance.

3.   Ensure system stability: Maintain the voltage and frequency stability of the DCMG under varying load conditions and solar irradiance levels.

4.   Minimize energy losses: Reduce energy losses during power conversion and transmission.

The remainder of this paper is organized as follows: Section II presents the system architecture and components. Section III discusses the proposed power management strategy, including the control algorithms and optimization techniques. Section IV presents the simulation results and experimental validation. Finally, Section V concludes the paper and outlines future research directions.

II. LITERATURE REVIEW

•   In [2012] The shortcomings of battery have attracted the researchers to develop a HESS for electric vehicle. UC is an energy storage device with high power density and therefore, it can be a good companion with the battery. Proper coordination between them will satisfy both high energy density as well as high power density

requirement of an EV. However, due to different performance characteristics of battery and UC, direct
connection between them is not possible [1].

• In [2015] Many HESS topologies are proposed in literature for the hybridization of more than one energy storage devices [2-5].

• In [2016] Parallel active topology enables independent control over the power flow of the battery and UC. It is also called as shared bus topology. During regenerative braking, the kinetic energy of the electric vehicle can be transferred to the supercapacitor or the battery by using appropriate switching algorithm for interfacing converters. This harvested energy can be used during acceleration and also for avoiding deep discharge of the battery [4].

• In [2018] The system efficiency can be improved by maintaining optimum dc bus voltage if HESS is designed to have the boosting features by connecting the dc/dc converter output in series with UC [5].

• In [2020] A HESS composed of battery, UC, one boost dc/dc converter and one bidirectional dc/dc converter with buck-boost feature, driving a PMDC motor. The control scheme ensures that the peak power demand of the load is shared by UC while base load is shared by battery. High pass and low pass filters along with tunable PI controller are implemented to ensure tight dc bus voltage regulation under various load conditions.

III. HYBRID ENERGY STORAGE SYSTEM

A. Functional Purpose of the HESS
Some of the major reasons for degradation of battery life are:
1) Heating effect in the battery due to the large value of draining current,
2) High magnitude ripple contents in the battery
3) Due to frequent charging/discharging in the battery.
Utilizing both battery and UC provides a compromise of high power density and high energy density energy storage system, resulting in compact, lightweight and high performance system. The electric powertrain of HESS based EV consists of three major components: DC/DC boost converter used to interface the battery with the DC link, another DC/DC converter used to interface the UC with the DC bus and the PMDC motor. Fig.1 demonstrates in the form of a block diagram, the main components and directions of power flow in the EV.
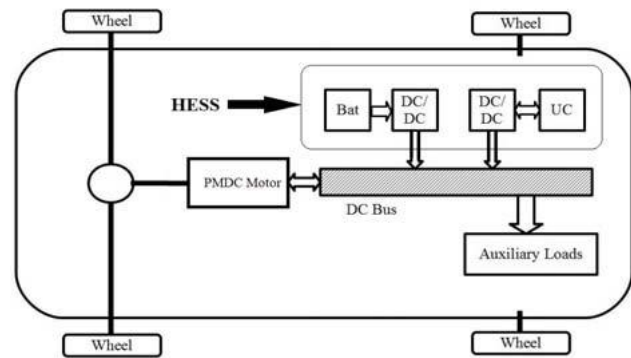

Fig.1. Block diagram representation of the proposed EV electric powertrain

B. Battery, UC and Motor selection

Now a days Li-ion battery is considered to be one of the advanced battery technologies available. The Li-ion technology has features like higher life cycles, high efficiency, and low self-discharge [14]. UC is a charge storing device which has the capability to provide short bursts of peak current. The low equivalent series resistance (ESR) of the UC ensures efficient operation but at the same time poses a threat to its operation due to large charging currents at lower state of charge (SOC) values. The performance difference between of various battery types and UC.

The electric motor use in EV should have high efficiency and the proper speed torque profile according to load requirement. Brushed and brushless Permanent Magnet DC motors are very popular for traction application. Brushless DC (BLDC) is a permanent magnet AC motor which is coupled with inverter and sensors, increases the overall size, cost, losses, and complexity of electric powertrain in EV. The above disadvantages will be overcome by replacing BLDC motor with brushed permanent magnet DC (PMDC) motor. PMDC motor eliminates the use of inverter and controller requirement because of its DC nature. The PMDC motor, the equation of voltage drop (ignoring voltage drop across the brushes) is given by Eq. (1) [16].

$$V = R_a I_a + K_E \Omega \tag{1}$$

The armature current I_a is [16]

$$I_a = (V - K_E \Omega)/R_a \tag{2}$$

Therefore, from Eq. (1), the torque T is [16]

$$T = K_T I_a = \frac{K_T}{R_a}(V - K_E \Omega) \tag{3}$$

Where, K_E = Back-e.m.f. constant

$\quad K_T$ = Torque constant

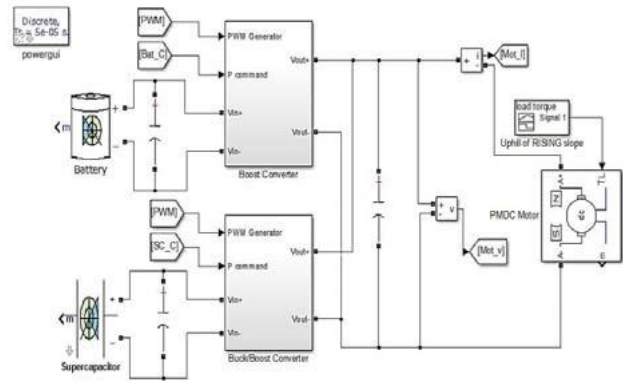$\quad \Omega$ = Rotational speed (rad/sec)

$\quad R_a$ = Armature resistance

Torque when motor is about to start is given by

$$T_S = \frac{K_T V}{R_a} \tag{4}$$

Rotational speed when motor has no load is given by,

$$\Omega_0 = \frac{V}{K_E} \tag{5}$$

C. Overall operation

The path of power flow changes according to the instantaneous requirement of the traction motor. The following are the various modes of operation of the HESS PMDC motor drive illustrated by Fig. 3.

1) Motoring Mode driving steady state

Only the battery supplies power to the traction motor and the motor operates in steady state. The DC link voltage is maintained at 25 volts

2) Motoring Mode during starting/ free acceleration

The traction motor draws high current leading to a fall in DC link voltage, the UC supplies a portion of this peak current demand so as to restore the DC link voltage.
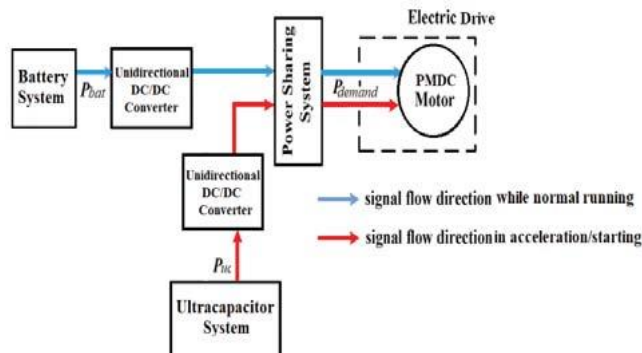

Fig.3. Block diagram showing overall operation

Fig.3.1 Simulink model

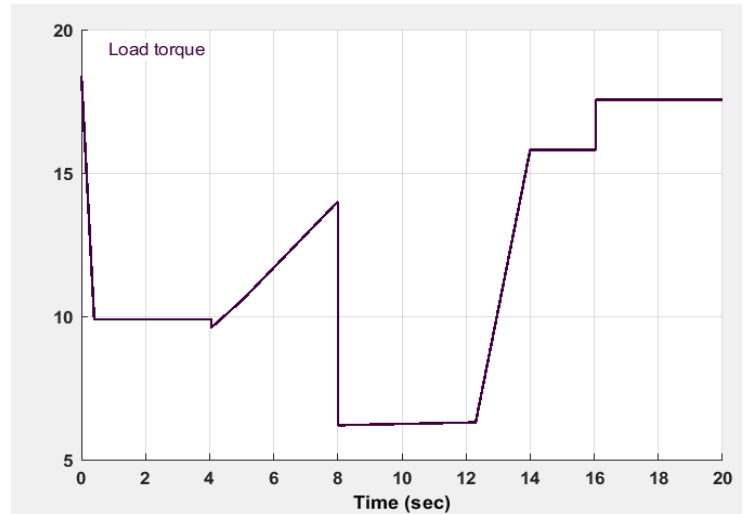## IV. RESULT ANALYSIS

- Simulation Results and Discussion

Fig. 4 Load Torque vs Time for electric vehicle

- Performance analysis of ESS under different load condition

A) Starting/Acceleration from Rest

In vehicles, during starting condition, the stiction demands very high starting torque to accelerate the motor from rest. This effect is simulated by applying a 5Nm load torque at zero speed and thereafter reducing it to 2 Nm at 0.4s. During this period, it is observed that, the overall power requirement of the motor is shared by battery as well as UC which discharges rapidly to 83% of its state of charge (SOC). The motor accelerates gradually and reaches to its steady state speed in 2.5s. At steady state, battery alone feeds power to the motor.

B) Running on a Positive Ramp

It is assumed that the EV is climbing on a road having a non linearly rising slope from 5.72s to 8.94s. This condition is simulated by applying a dynamic torque increasing from 2 to 4 Nm. The lagging of motor torque behind the load torque results in a speed drop of 25%. From Fig. 3(d), it is observed that, the transient rise in load torque activates the inner control loop of Fig. 2 and to relieve the battery from draining rapidly, the peak power is supplied by UC. In this process, it discharges at a faster rate reaching to 72% of its SOC. Thereafter, during steady state, the battery supplies power to the motor as well as UC for charging.

C) Regenerative Braking
At 14.3s, the vehicle is assumed to run on a downward slope with continuously rising speed at a constant rate. This condition is simulated by assuming a constant negative dynamic torque of 2 Nm from 14.3s to 16s. The speed rises above normal value and the tractive machine acts as a generator. The kinetic energy of wheels is converted into electrical energy and is used to charge the on board capacitor thus increasing its SOC. Due to reversal of motor current, a braking torque is developed which opposes the increasing speed of the vehicle.

In vehicles, static friction during the starting state requires a very high starting torque to accelerate the engine from standstill. This effect is simulated by applying a load torque of 5 Nm at zero speed and then reducing it to 2 Nm in 0.4 s. During this time, it is observed that the total power requirement of the motor is shared by both the battery and the UC, which rapidly discharges to 83% of its state of charge (SOC). The motor gradually accelerates and reaches steady state speed in 2.5 s. In steady state, only the battery purchases electricity to the motor.
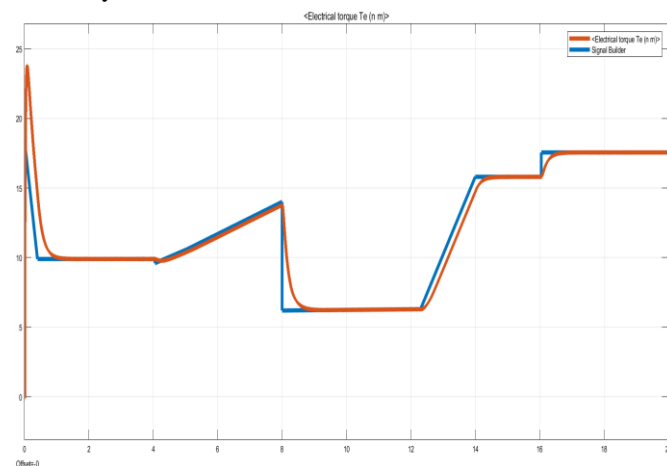

Fig.5 Comparison of Electrical Load Torque (N-m) with signal Builder for electric vehicle

The electric vehicle is implicit to travel uphill on a road with a slope that does not increase linearly from 5.72 s to 8.94 s. This

condition is simulated by applying a dynamic torque that increases from 2 to 4 Nm.
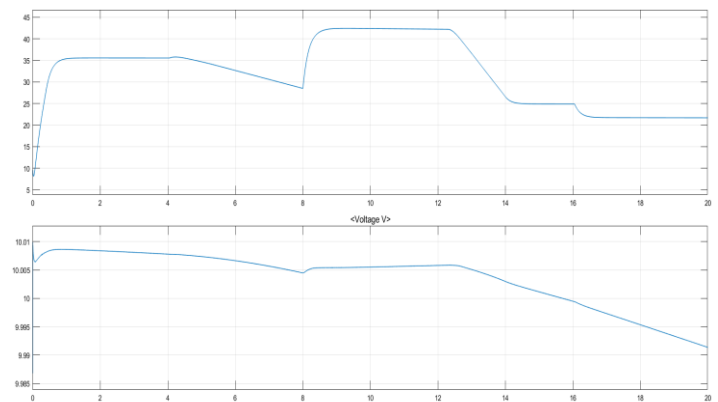

Figure 6 Load Torque vs Time for electric vehicle

The lag of the motor torque behind the load torque leads to a speed drop of 25%. In Figure. 3 (d) it can be understood that the transient increase in load torque activates the inner loop of Figure. 2 and to free the battery from a rapid discharge, UC supplies the maximum power. In this process, it discharges faster and reaches 72% of its COS. After that, the battery provides power to the motor and UC to charge during steady state
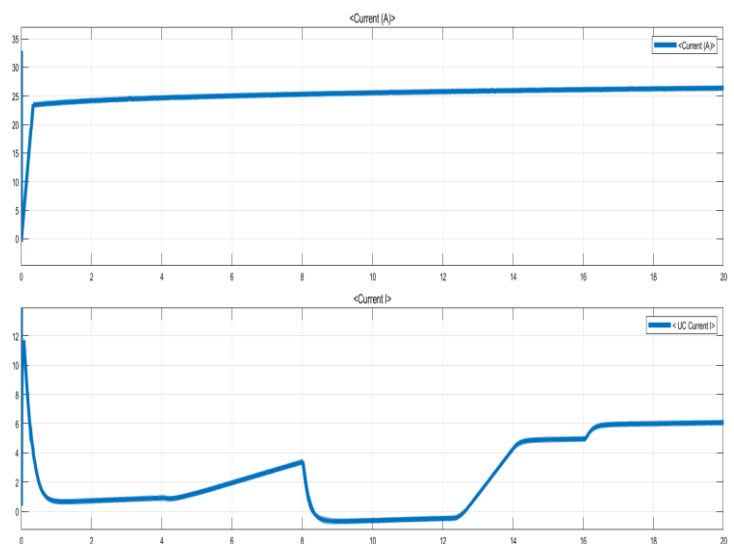

Fig.7 Battery & UC Current Waveforms in different operating condition

At 14.3 s the vehicle is assumed to travel at a constant speed on a slope with a continuously increasing speed. This condition is simulated assuming a constant negative dynamic torque of 2 Nm from 14.3 s to 16 s. The speed is raised above normal and the tractor acts as a generator. The kinetic energy from the wheels is changed into electrical energy and used to charge the on-board capacitor, increasing its SOC. By

reversing the motor current, a braking torque is generated that counteracts the increase in vehicle speed.
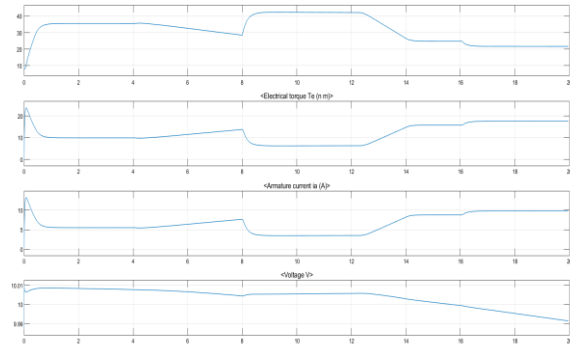

Fig.8 Speed torque Armature current and dc link voltage waveform.

The result shows that whenever the charge current changes, the ultra-capacitor can respond immediately to the change in charge current by letting the battery slowly meet the charge demand. Since the battery is only exposed to a slowly changing charging current and provides only a fraction of the charging current requirement, the battery is exposed to a lower frequency component of the charging current change that causes the charging current to the battery changes smoothly and thus extends to a contributes to battery life. This type of energy storage scheme prolongs the life of the battery

The simulation results show the performance of the suggested scheme during starting, driving, regenerative braking and steady state. The control scheme, which is designed to maintain a constant value of the DC bus voltage, generates the necessary switching pulses for the converter devices and ensures proper direction of the power flow. Although the bus voltage is fixed at the rated motor voltage, it has been observed that it tends to drift under dynamic conditions.
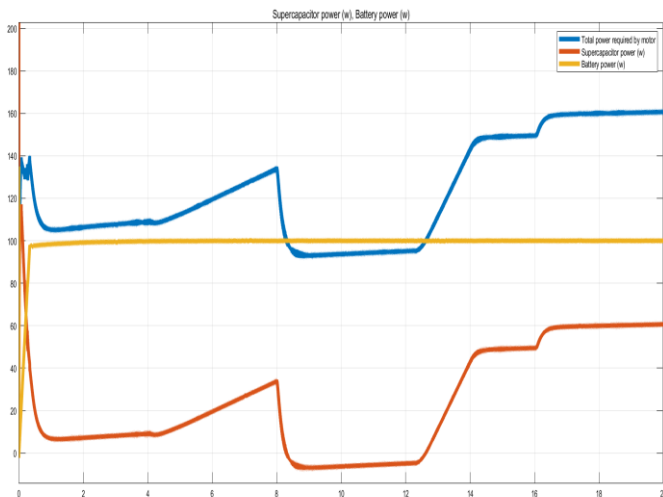

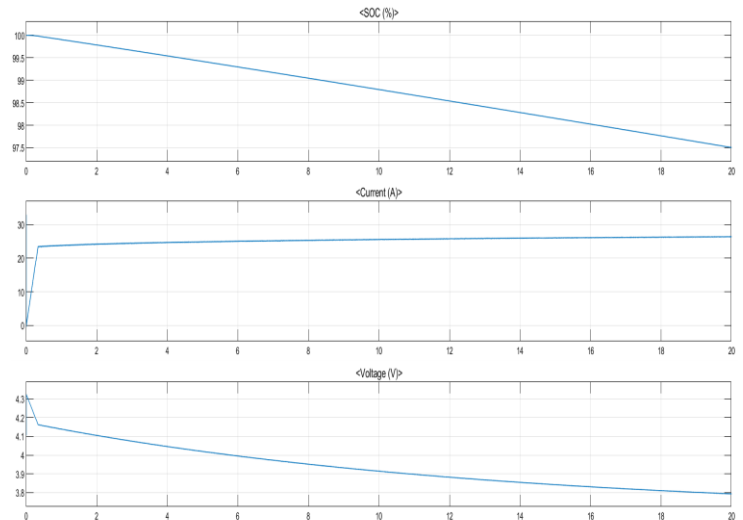Fig.9 Total Power required by the motor, Supercapacitor Power, Battery Power (Watt)

Fig.10 Battery and UC SOC in different operating conditions

UC charging and discharging attempts to maintain its SOC, but due to the 's unidirectional power flow allowed for the battery, its SOC continues to decrease with operation. However, it is evident that due to the reduction of the maximum battery charge, the drop in its SOC is less in the proposed HESS compared to a battery-only schem.

VI. CONCLUSION

Two different sources (battery and UC) based HESS has been developed for the EV. The closed loop PI controller based energy management algorithm has been simulated to verify the designed system. For the effective use of battery, individual DC/DC boost converters have been implemented between battery, UC and regulated DC link voltage. The speed
of the dc motor was indirectly controlled by controlling the DC link voltage. From the simulation results, it was verified that the load transients were compensated by the UC during transient condition and the battery provides average power during steady state condition.

VII. SCOPE OF IMPROVEMENT

Regenerative braking mode can also be implemented in the proposed HESS model in which the traction motor operates as generator, this will charge the onboard UCs from the kinetic energy which otherwise is wasted while applying brakes. For the addition of this mode in overall operation, the unidirectional boost converter between UC and DC link should be replace with bidirectional DC/DC converter to charge the UC.

REFERENCES

[1] A. Emadi and M. Ehsani et al, "Modern Electric, Hybrid Electric, and Fuel Cell Vehicles Fundamentals, Theory, and Design," Boca Raton, FL: CRC Press,, vol. 2, 2004.

[2] "Electrical .Energy .Storage," .International .Electrochemical .Commission, . .EES.IEC .ISBN .978-2-88912-889-1, .2011-12.

[3] .J. .Larminie .and .J. .Lowry, .et .al, ."Electric .Vehicle .Technology .Explained," .John .Wiley .Sons .Ltd. .2003.

[4] .Z. .Khaligh .et .al, . ."Battery, .Ultra-capacitor .Fuel .cell .and .Hybrid .Energy .Storage .Schemes .for .Electric .Hybrid .Electric .Fuel .cell .and .Plug-in .Hybrid .Electric .Vehicles," .IEEE .Transactions .on .Vehicular .Technology, .vol. .59, .no. .6, .pp. .2806–2814, .Sept .2010. .

[5] .J. .Chris .and .A. .Masrur .et .al, ."Fundamentals .of .Hybrid .Electric .Vehicles .Seminar," .SAE .International, .2006. .SAE .Congress, .p. .414, .2010. .

[6] ."Styles, .geoffrey. .What .Peak .Oil?," .Energy .Tribune, .6 .25, .2010. .

[7] C. .Sinkaram, ."Modeling .Battery .Management .Scheme .using .the .Lithiumion .battery," .Power .Electronics, .IEEE .Transactions .on, .pp. .1509–1522, .April .2011. .

[8] J. .Cao .et .al, ."A .New .Battery/ultra-capacitor .Hybrid .Energy .Storage .Scheme .for .Electric .Hybrid .and .Plug-in .Hybrid .Electric .Vehicles", .VPPC .'09. .IEEE, .pp. .941–946, .sept .2009. .

[9] N. .Jalil .et .al, . ."A .Rule-Based .Energy .Management .Strategy .for .a .Series .Hybrid .Vehicle," .Presented .at .Proceedings .of .the .American .Control .Conference. .

[10] S. .Lukic .et .al, . ."Energy .storage .schemes .for .Automotive .applications," .Industrial .Electronics, .IEEE .Transactions .on, .pp. .2258– .2267, .June .2008. .42 .

[11] .P. .A. .Cassani .et .al, ."Design ., .Testing .and .Validation .of .a .Simplified .Control .Scheme .for .a .Novel .Plug-in .Hybrid .Electric .Vehicle .Battery .Cell .Equalizer," .Industrial .Electronics, .IEEE .Transactions .on, .pp. .3956–3962, .2010. .

[12] .P. .A. .Cassani .et .al, ."Feasibility .Analysis .of .a .Novel .Cell .Equalizer .Topology .for .Plug-in .Hybrid .Electric .Vehicle .Energy-Storage .Schemes," .IEEE .Transactions .on .Vehicular .Technology, .pp. .3938–3946, .2009. .