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Design and Control of Hybrid Power Supply for HEV

PREPARED BY : Prof. Varsha Shah

Department of Electrical Engineering

Sardar Vallabhbhai National Institute of Technology

Surat

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- SYSTEM CONFIGURATION AND OPERATIONAL MODES
- ENERGY MANAGEMENT ALGORITHM
- CONTROL ALGORITHMS
- SYSTEM OPERATION WITH VARYING LOAD
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INTRODUCTION

- Reliable alternative for transportation
- HEV concentrates in the search for compact, lightweight and efficient energy storage system that is affordable as well as having acceptable life cycle.
- HEV has electrical and mechanical propulsion system which operates independently or together.
- Create a high power and high energy electric storage system that has equal or better system efficiency and cost/ density as current conventional battery.
- HEV utilizes a combination of ultracapacitor and battery is proposed to meet the rapidly changing energy and power requirements.

INTRODUCTION

- To optimize the performance of both energy storage devices in terms of power flow from source to load and vice-versa, there arise a need for power electronic converter.

- To ensure
  - Constant DC bus voltage
  - To minimize inductor current and output voltage ripple

- Dynamic evaluation control algorithm has been proposed

- Power sharing between battery and ultracapacitor as well as IC Engine is implemented using rule based energy management algorithm

Energy Storage Devices

- Valve Regulated Lead-Acid (VRLA),
- Lithium-ion batteries
- Nickel-metal hydride batteries
- Lithium-polymer batteries
- Ultracapacitors
- Flywheels

Energy Storage System Characteristics Required for Vehicle Applications

- High energy density for driving range.
- High power density for acceleration.
- Capacity to absorb power during regenerative braking.
- Trade-offs between power density W/kg and energy density Wh/kg become important for vehicle applications.
- Variation of power density with SOC and charge/discharge can be important.
- Very high cycle life is needed.

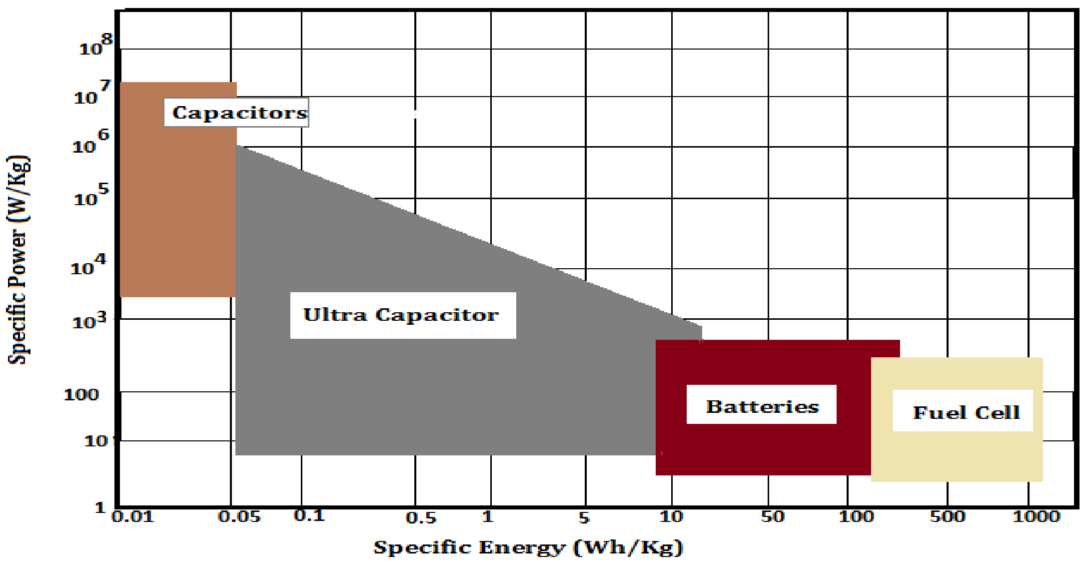
Comparison of Conventional Storage Technologies

Available Performance	Lead Acid Battery	UC	Electrolytic Capacitor
Charge Time	1 to 5 hrs	0.3 to 30 s	10-3 to 10-6s
Discharge Time	0.3 to 3 hrs	0.3 to 30 s	10-3 to 10-6s
Energy (Wh/kg)	10 to 100	1 to 10	< 0.1
Cycle Life	1,000	>500,000	> 500,000
Specific Power (W/kg)	<1000	<10,000	> 100,000
Charge/discharge efficiency	0.7 to 0.85	0.85 to 0.98	> 0.95

Reasons for Battery Ultracapacitor Hybridization

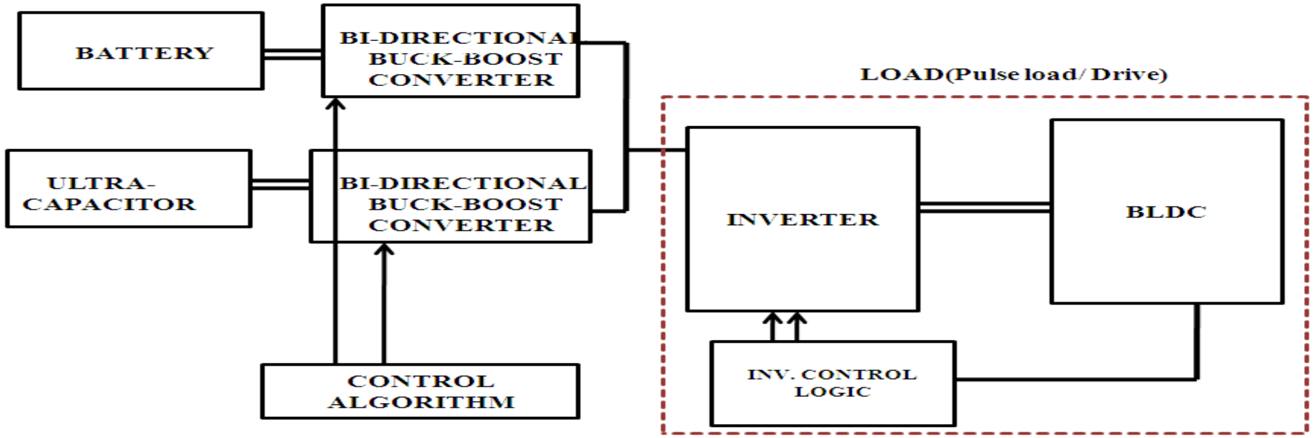
- High Specific Power with High Specific Energy
- Higher Energy Efficiency for Battery
- Effective Regenerative Braking
- Improved Battery Life and Smaller Battery Pack

Regon plot

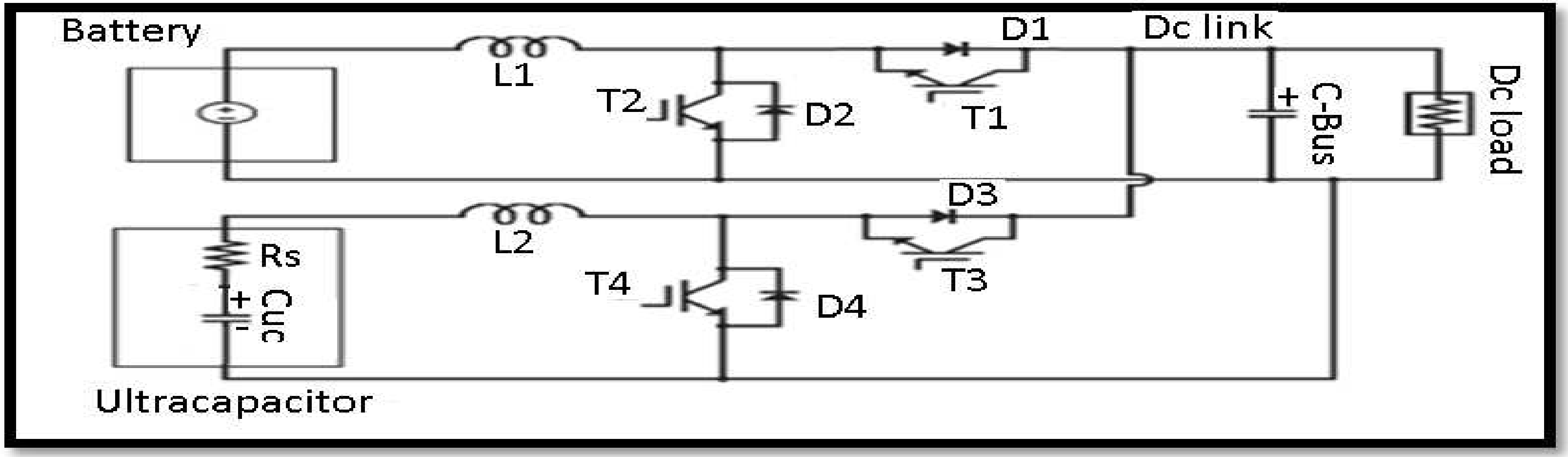


System Configuration and Operational modes

- ❑ **Basic Block Diagram :**



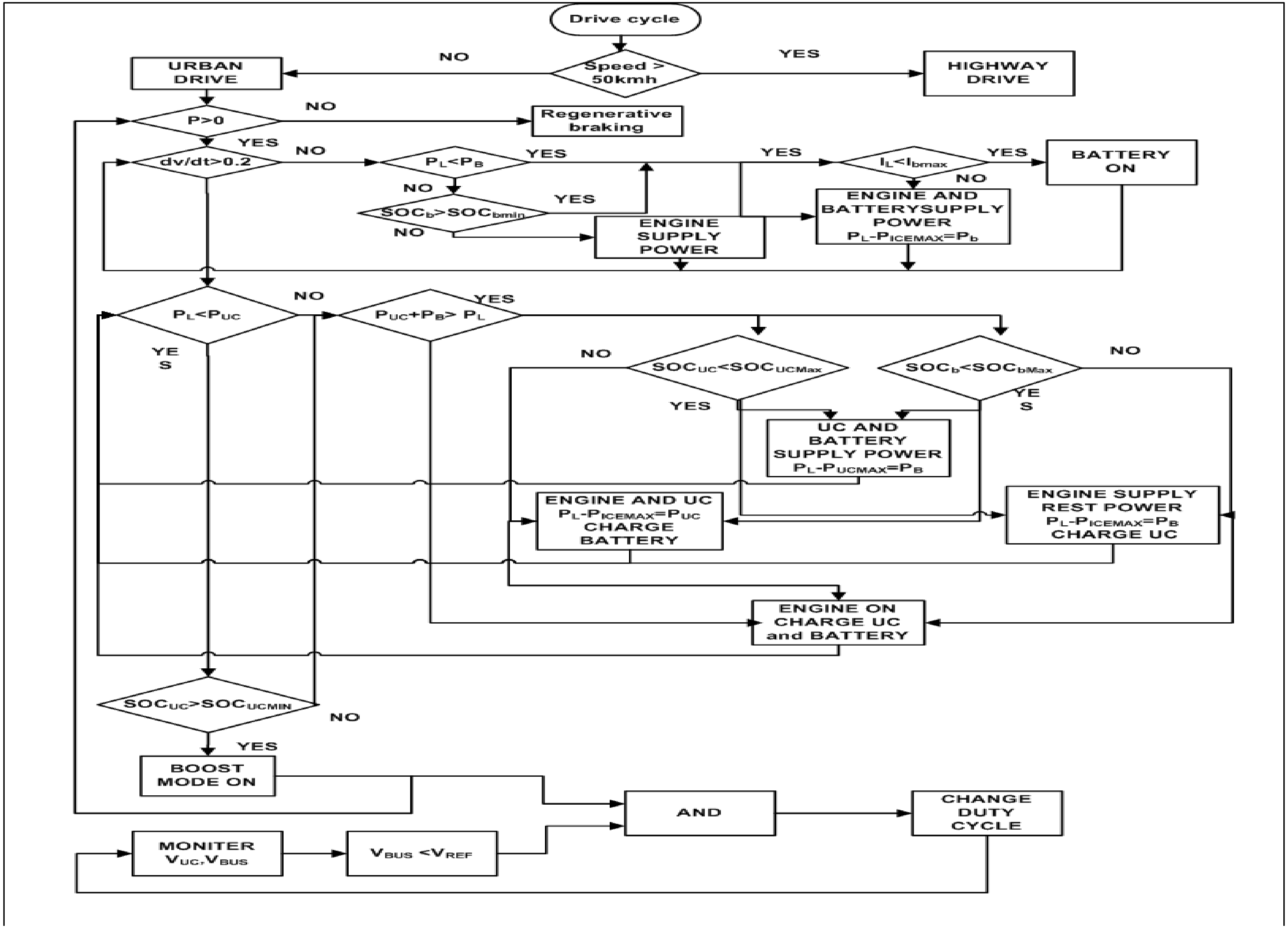
- ❑ **Circuit Configuration:**



Operating modes

- The whole system operates in 3 different modes.
- Initial assumption - Battery and UC are 100 % charged before the operation start.
- Peak power mode - When motor is accelerated from zero speed under constant load, the current demanded by motor is very high compared to rated current. Under this condition power is supplied by ultracapacitor.
- Normal mode – When the load current demand is lower than rated battery current, then the load current is supplied by battery only. Depending upon the load current and SOC of battery, Battery may charge UC.
- Regenerative mode – During regeneration, motor shaft gains kinetic energy due to its own inertia and load inertia. This kinetic energy is converted into electrical energy to charge the ultracapacitor.

Urban Drive Energy Management Flow Chart



Control Algorithm for Boost Converter

- An early approach
- Transfer function where the state of the system are averaged around a nominal operating point may fall short when there are disturbances in the systems.
- Constant frequency PWM based control technique
- problem of inherent instability and sub harmonic oscillation
- compensator network
- fuzzy, linear quadratic, passivity based, sliding mode control
- robust in nature
- good performance
- complex in design and implementation

Control Algorithm

- **Dynamic Evaluation Control Algorithm**

  - **DC to DC boost converter operation is controlled through dynamic evaluation control algorithm to take power from ultracapacitor and battery during acceleration mode and average power demand mode.**

- **Hysteresis Control Algorithm**

  - **DC to DC buck converter operation under braking mode is controlled through hysteresis control algorithm to return kinetic energy to battery and ultracapacitor.**

Dynamic Evaluation Control Algorithm

❑ Basic idea is to reduce the error state by forcing the error to follow exponential evolution path , allowing it to decrease it to zero.

❑ Dynamic evolution path

$$E = Eo * e^{-mt} \qquad \frac{dE}{dt} + m * E = 0$$

- E is the dynamic characteristic of the system,
- Eo is the initial value of E
- m is a design parameter specifying the rate of evolution.
- Higher the value of m lesser will be the time taken by the error to reduce it to zero.
- In DC to DC converter this control law is corresponds to the duty cycle equation of the converter.

Dynamic Evaluation Control Algorithm

Based on the state space average model,

The voltage and current dynamics of the boost converter

. $L + V_{out} *[1-D]\, V_{in} + i_L*R=0$

R is the system resistance which is equivalent to $R_{esr}+R_L+R_D$,

Vuc is the input voltage,

Vout is the output voltage,

Dynamic evaluation controller is began with state error function E and in power electronics application it is either voltage or current error.

$$E = k*Verr$$

k i $\frac{dE}{dt} = k * \frac{dVerr}{dt}$ ive coefficient, Verr is the error voltage.

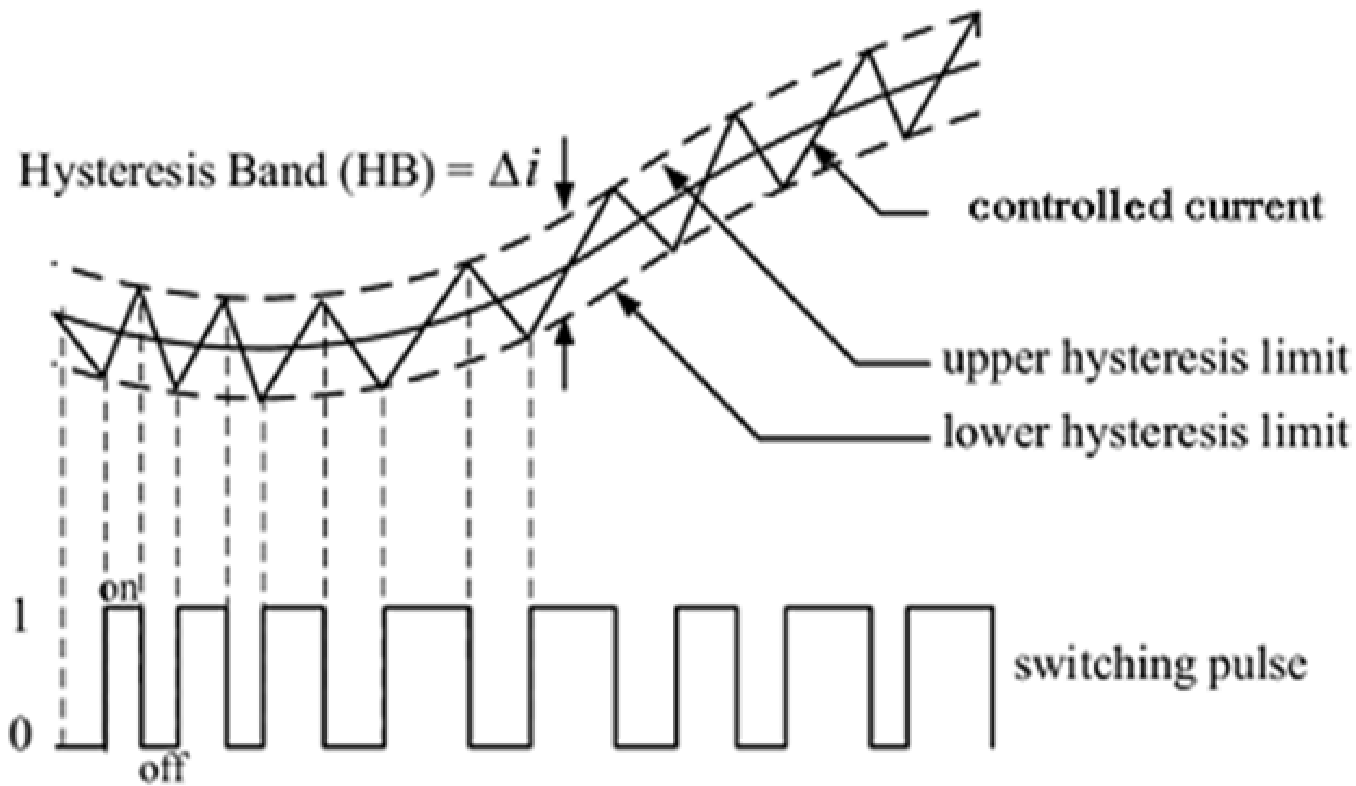
$$D = \frac{Vref - Vuc}{Vout} + \frac{(m * k - 1) * Verr}{Vout} + \frac{k * \frac{dVerr}{dt}}{Vout} + \frac{L * \frac{diL}{dt}}{Vout} + \frac{iL * R}{Vout}$$

Dynamic Evaluation Control Algorithm

- This algorithm can compensate all variations in the input and output voltages, load current and inductor currents.
- Better dynamic performance
- Good response to error converging speed
- Duty cycle forces the state error function to make evolution following exponential function and to decrease to zero with reduce rate of m.

Hysteresis Control Algorithm for Buck mode operation

Hysteresis Algorithm Based Pulse Generation



Hysteresis Control Algorithm

- In this control, two current references I_uref (upper band reference), I_lref (lower band reference) are generated, one for the peak and the other for the valley of the inductor current.
- According to this control technique, the switch is turned on when the inductor current goes below the lower reference I_lref and is turned off when the inductor current goes above the upper reference I_uref , giving rise to variable frequency control.
- These current swings are used to charge the ultracapacitor and thus the controlled current enters it contributing to improve the charging efficiency.

Hysteresis Control Algorithm

- In above topology mentioned the buck mode switching is provided by hysteresis current band control based on sensing the inductor current.
- These swings has the disadvantage that the modulation frequency varies in a band and as a result, generates non optimum current ripple in the ultracapacitor.
- As a result, the ultracapacitor current causes a little bit additional heating.

System Operation with Varying Load

❖ Performance of whole system is carried out in matlab simulink under different load.

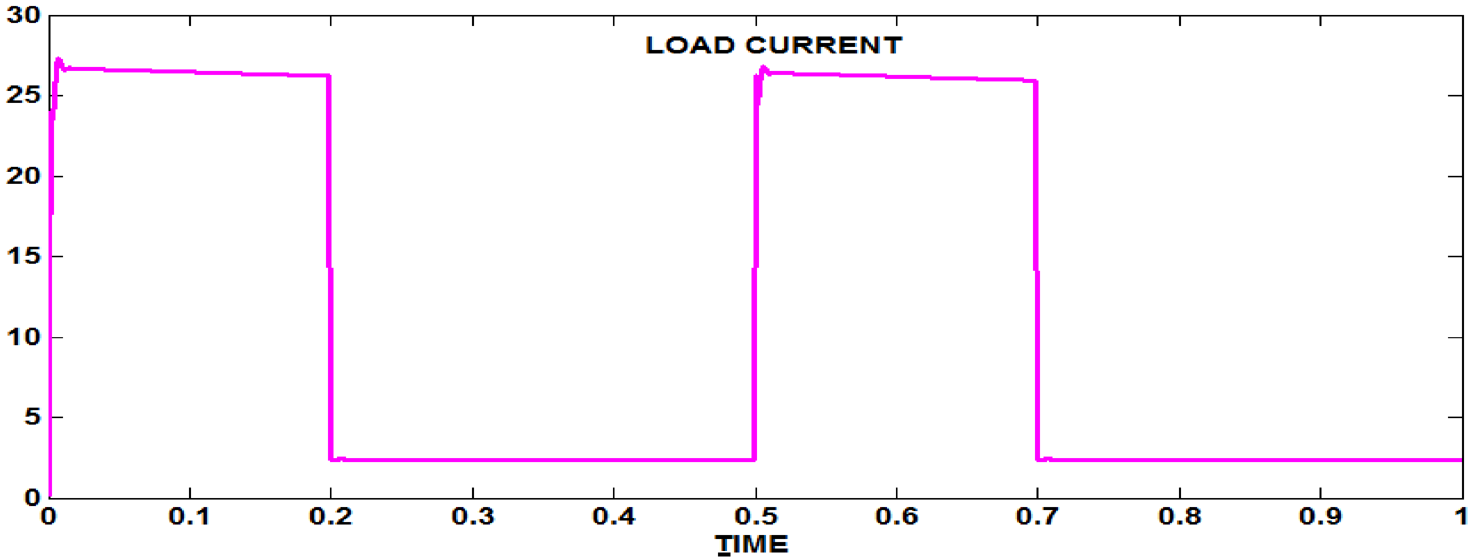
❖ The goal is to maintain dc bus voltage constant with minimum ripple.

❖ Battery: 24 V, 20 Ah , L = 10 Micro Henry,

❖ Ultracapacitor : 27.5 V, 60 F, C = 1500 Micro Fereday.

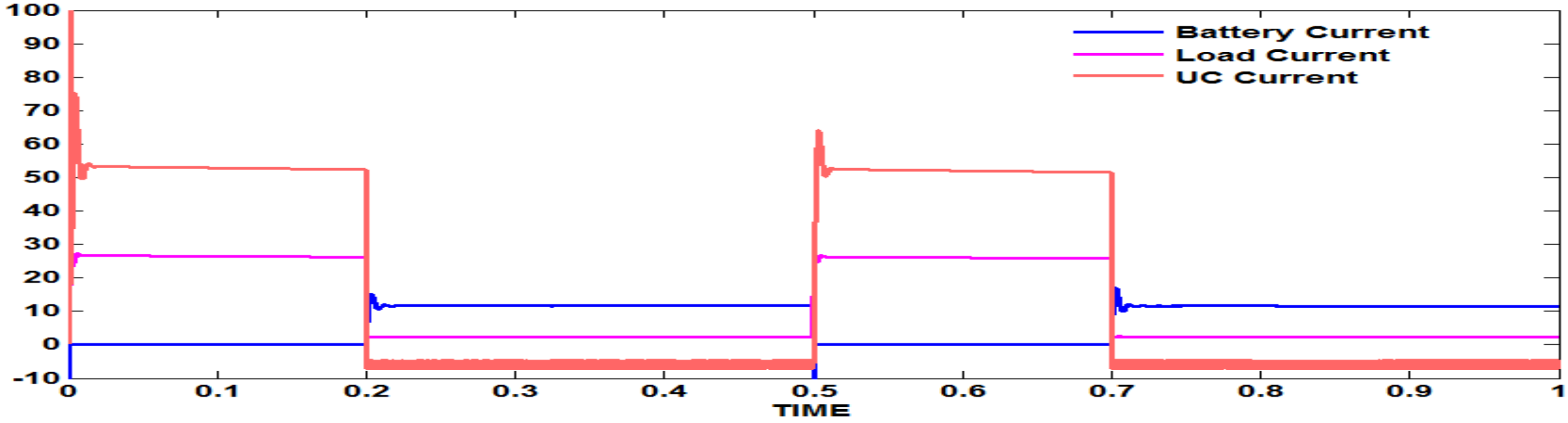
❖ **Pulse Load**

- ❖ The EV and HEV operate with common load profile, described by relatively high peak to average power required.
- ❖ This type of load can be very closely represented by repetitive cycle of pulse load with constant peak and average current.

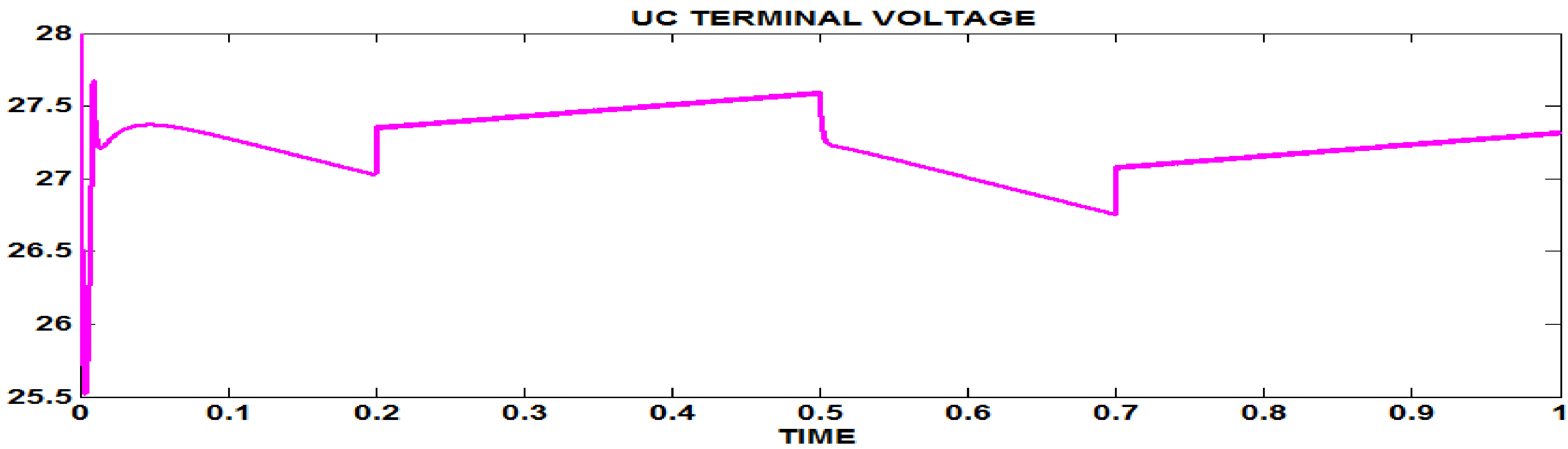


System Operation with Varying Load

Current Distribution among UC and Battery Based on Load Current

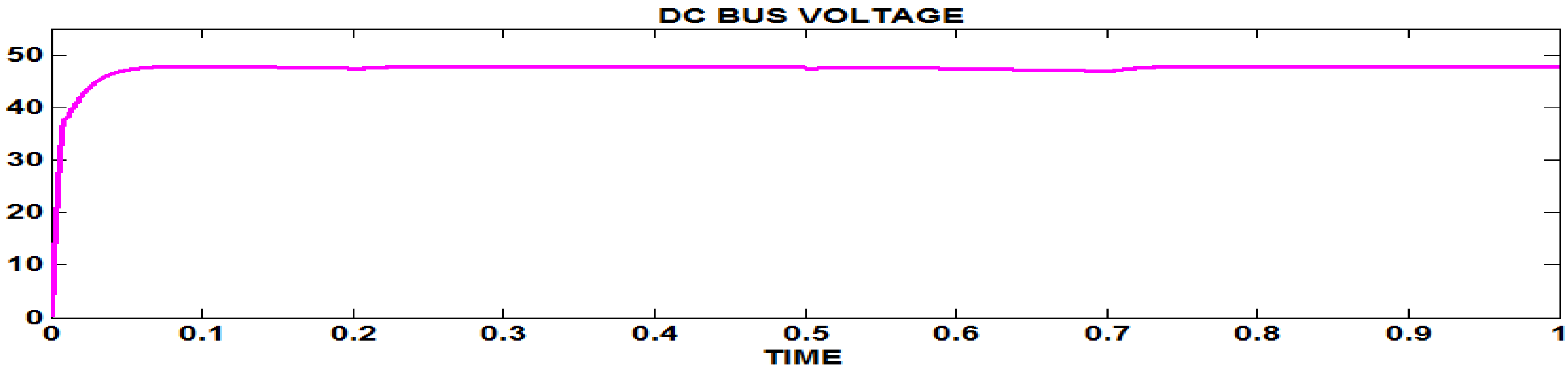


UC Terminal Voltage



System Operation with Varying Load

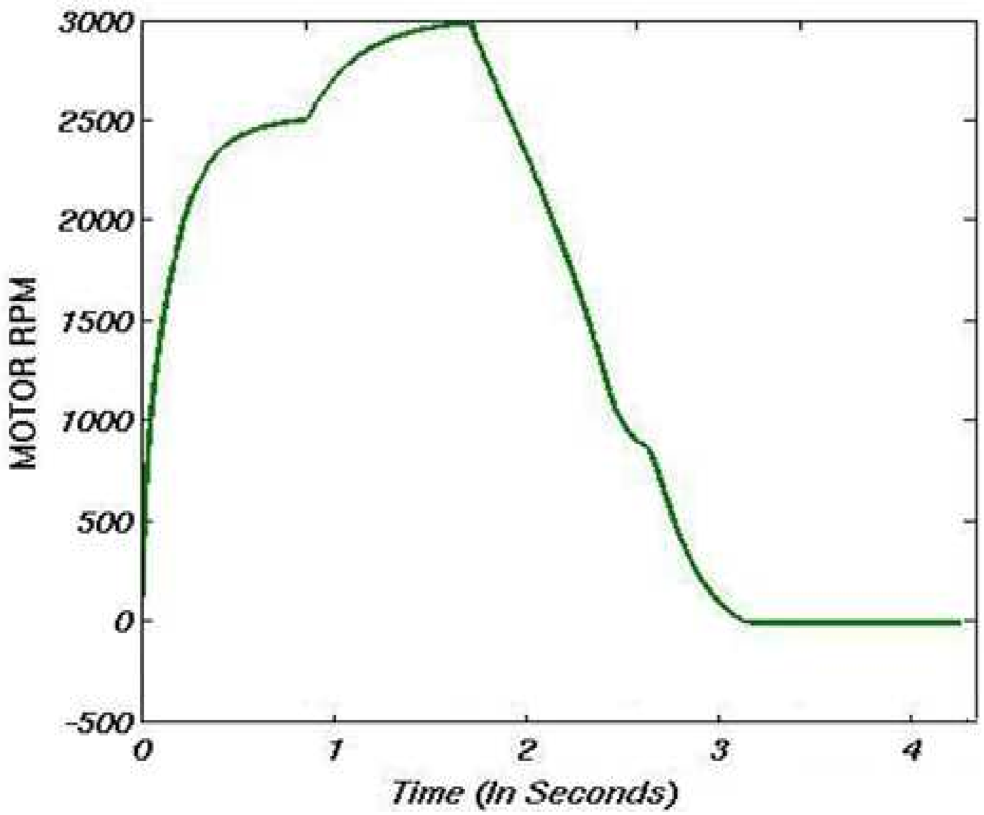
DC Bus Voltage



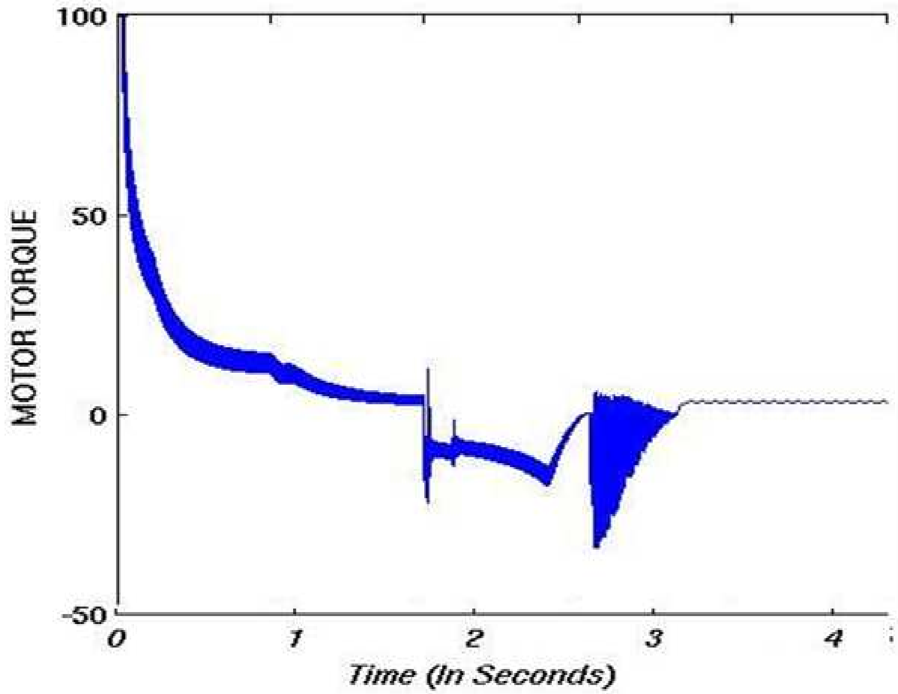
PMBLDC Drive With Constant Load Torque

Control of BLDC motor in both motoring mode and regenerative mode is applied with help of sensing rotor position.
Ultracapacitor 48 volts, 83.33 F
BLDC Motor 48 volts, 3000rpm, 10 kw

Motor Speed in RPM

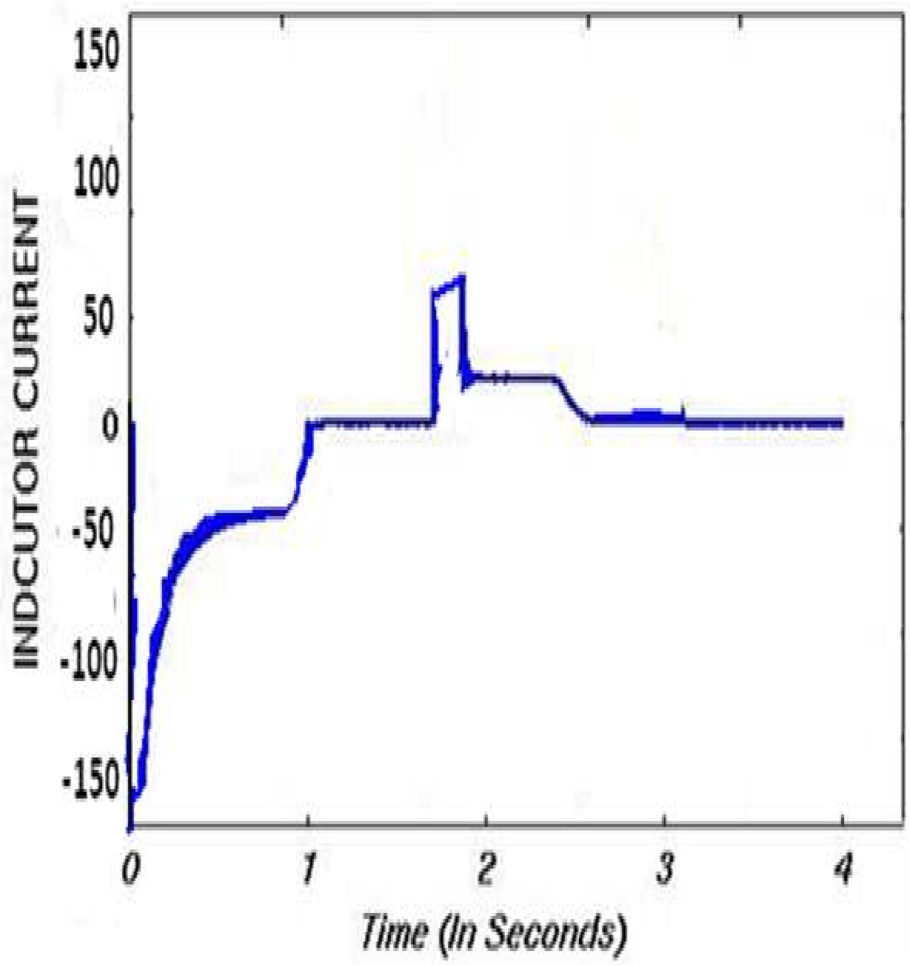


Motor Torque

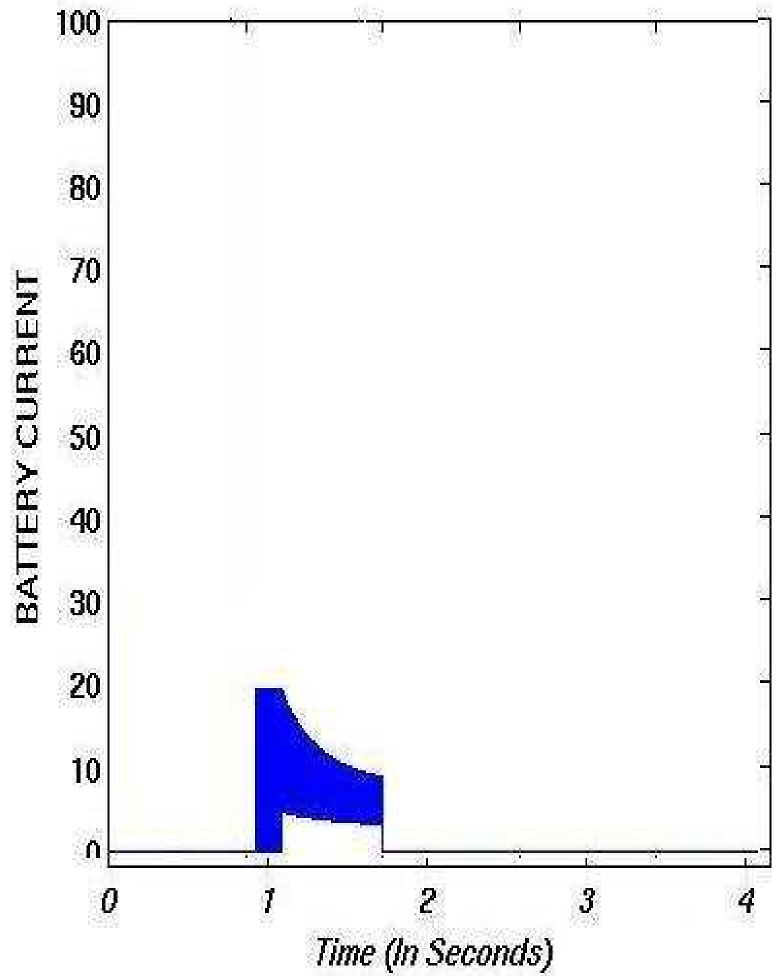


PMBLDC Drive With Constant Load Torque

Inductor Current

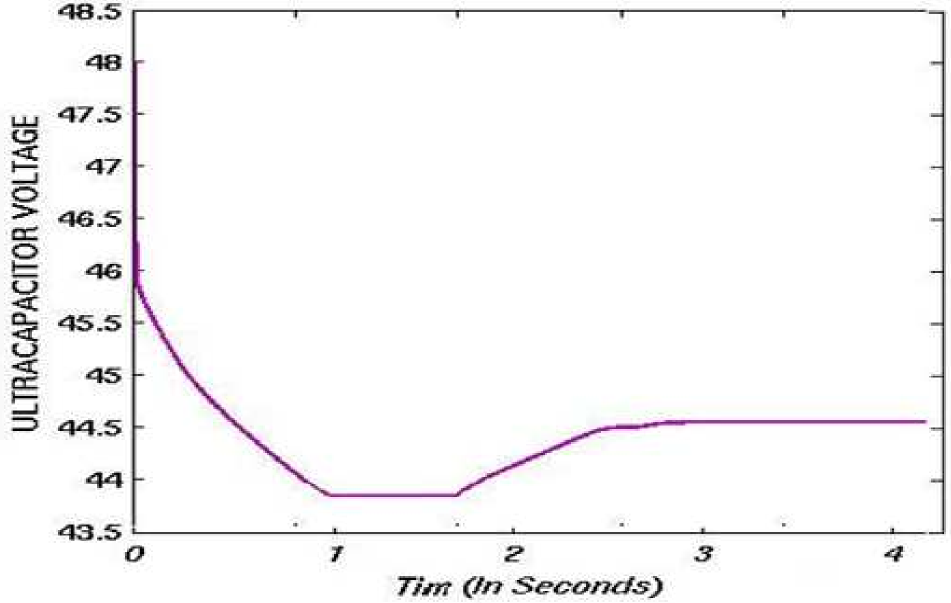


Battery Current

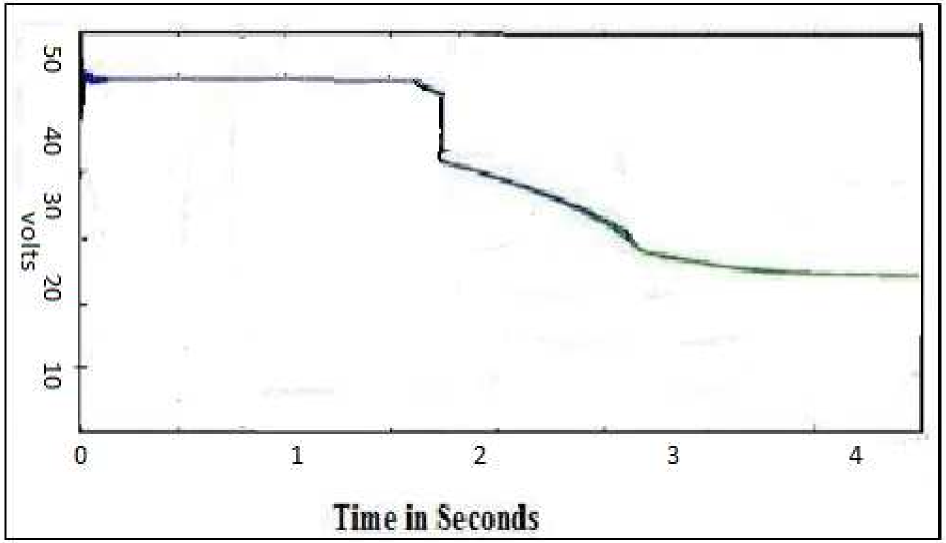


PMBLDC Drive With Constant Load Torque

Ultracapacitor Voltage



DC Bus Voltage



Conclusion

- **The battery-ultracapacitor hybridization can bring significant benefits to hybrid electric vehicles.**

- **DC bus voltage with a ripple of ± 2V under continuously varying load and input voltage of UC is maintained constant using dynamic control algorithm.**

- **The operation of an active hybrid results in a much lower battery current with very small ripples, avoiding the deep charge-discharge of the battery and therefore a lower battery temperature and longer battery lifetime.**

- **Under regeneration kinetic energy is absorbed by UC which improves the efficiency of hybrid storage system.**

THANK YOU

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