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Power Electronics Solutions for Efficient Energy Conversion in Electric Vehicles

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Abstract *– This paper presents a Voltage imbalance issues in series stacking of UCs are addressed by increasing the conversion gain of MMCC. The selection of conversion gain involves balancing UC capacitance, the number of parallel stacks, and cost considerations. The thesis provides detailed guidelines for determining the optimal voltage gain of MMCC, considering these factors. Additionally, a failure mode analysis of the MMCC converter highlights its performance under fault conditions.*

A comprehensive comparative study of EVs employing Battery Energy Storage Systems (BESS) and hybrid energy storage systems is presented to elucidate the advantages of HESS. Economic feasibility assessments of BESS and HESS underscore the effectiveness of Li-ion battery/UC HESS.

The converter topology and energy management control schemes proposed in this thesis are expected to pave the way for novel approaches to hybridizing energy sources for EV applications.

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Keywords: Electric Vehicles, Power Converter, DC-DC Converter, UC, Baterry Hybrid Power, MMCCC

I. INTRODUCTION

The global energy scarcity is escalating due to the gradual depletion of fossil fuel reserves. According to a worldwide energy consumption report, the transportation sector accounts for one-third of the world's total energy consumption, as depicted in Figure 1, and this consumption is increasing at an average annual rate of 1.4%. With concerns mounting over dwindling fossil fuels and rising air pollution, the transportation sector is seeking alternative fuel solutions to facilitate green transportation.

The advancement of hybrid electric cars (HEVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell electric vehicles (FEVs) marks the initial stage of transitioning from conventional fuel vehicles to alternative fuel vehicles. These vehicles feature fuel-efficient engines that consume minimal gasoline, emit reduced noise levels, and are capable of recovering energy during braking. Addressing urban transportation emissions is critical, given that more than half of the global population lives in cities, where they contribute to 70% of the world's CO2 emissions. For zero-emission transportation, pure electric vehicles emerge as the ideal choice.

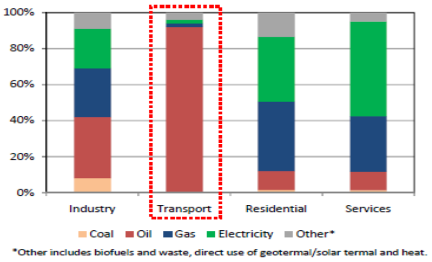


Figure 1 Illustrates the global consumption of energy sources, as reported by Herrera in 2017.

The cornerstone of electric vehicles (EVs), ensuring reliable operation (Alireza et al., 2010). The primary criteria influencing the selection of (ESS) for an electric vehicle (EV) include operational qualities, weight, volume, cost, temperature range, and response time (Un-Noor et al., 2017). Among the different options, batteries have emerged as the most established ESS for EV applications. With advancements in battery technology, As depicted in Figure 2, Li-ion batteries have demonstrated significant superiority compared to other varieties (Yu Miao et al., 2019). Li-ion batteries offer high specific energy, crucial for enhancing driving range (Lia Kouchachvili et al., 2018), along with longer cycle life and improved efficiency. However, relying solely on Li-ion batteries may not fulfill all the requirements of a pure EV. Therefore, there is a growing emphasis on hybridizing ESS, which involves integrating multiple energy sources with complementary features (Miller et al., 2009).

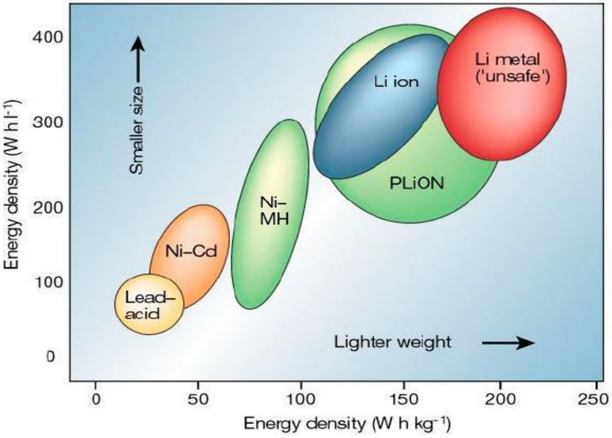


Figure 2: Ragone plots of various battery technologies(Source: Yu Miao et al.,

II . Hybrid Battery and Ultra Capacitors Model

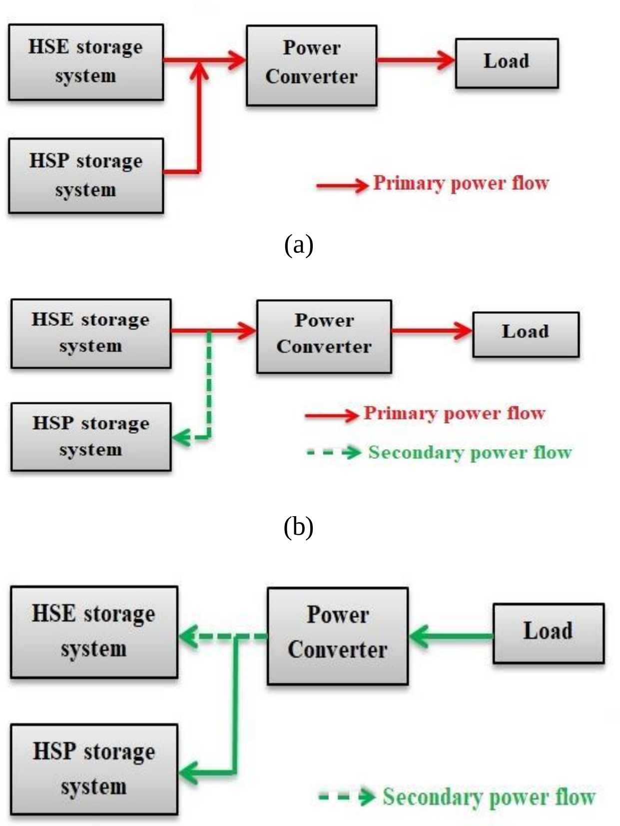
Grid The integration of batteries and ultracapacitors (UCs) in electric vehicles (EVs), known as hybridization, has garnered considerable interest in the research and development domain due to its myriad advantages. Here are some significant points regarding battery and UC hybridization:

Complementary Characteristics: Batteries and ultracapacitors possess complementary characteristics that make them suitable for hybridization. Batteries are known for their high energy density, which allows them to store large amounts of energy for longer durations, making them ideal for providing sustained power over extended periods. On the other hand, ultracapacitors have high power density and can rapidly charge and discharge, making them well-suited for delivering bursts of power during acceleration or regenerative braking.Enhanced Performance: By combining the strengths of both battery and UC technologies, hybrid energy storage systems (HESS) can achieve enhanced performance compared to standalone systems. The battery can handle the steady-state energy requirements of the vehicle, while the ultracapacitor can provide additional power during peak demand situations, such as sudden acceleration or regenerative braking.Improved EfficiencyCombining batteries and ultracapacitors (UCs) in hybridization may boost the total efficiency of the energy storage system by up to three points. Ultracapacitors possess attributes such as rapid energy capture and release, minimal energy loss during charging, and high efficiency in energy storage.

By leveraging these capabilities, the hybrid energy storage system (HESS) can optimize energy utilization and enhance the vehicle's overall efficiency across discharge cycles. This integration enables HESS to reduce energy wastage and maximize the utilization of both the battery and UC components. Extended Battery Life: One of the challenges with conventional battery systems is the degradation of battery life due to high charge-discharge cycles and peak power demands. By offloading high-power demands to the ultracapacitor, HESS can reduce the strain on the battery, leading to extended battery life and improved longevity of the overall energy storage system.

Regenerative Braking: Ultracapacitors are particularly well-suited for capturing energy during regenerative braking, where kinetic energy from braking is converted into electrical energy and stored for later use. By efficiently capturing and storing this energy, HESS can enhance the vehicle's overall energy efficiency and reduce reliance on external charging sources. Figure 4.1 illustrates the idea of combining battery and ultracapacitor (UC) for various vehicle operating conditions.

As seen in Figure 2(a), in instances of high power demand, the High-Speed Energy Storage System (HSESS) supplies top load, while the Hybrid Storage System (HSESS) produces three steady power. As below fig 2.(b), when the demand for power drops, the HSE storage system powers the load while also charging the HSP storage system according to its state-of-charge (SOC) status. As seen in Figure 2.1(c), the braking power produced during regeneration moves.



(a)

(b)

(c)

Figure 2 illustrates the hybridization of Energy Storage Systems (ESS) for various operating conditions

(a) During power demand motoring conditions, the load receives peak power from the High-Speed Power Storage System (HSPSS), while the Hybrid Storage System (HSESS) supplies continuous power.

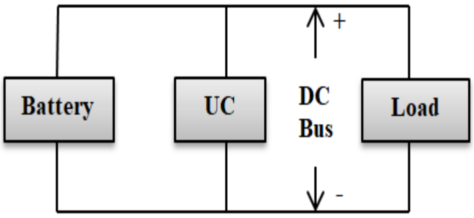
(b) In situations when it wants low power during motoring conditions, the HSE storage system powers contingent upon the state-of-charge (SOC) status.

(c) During regenerative braking conditions, the generated power of breaking is transferred to ESS for regeneration. (Source: Joao P. Trovao & Paulo G. Pereirinha, 2012)

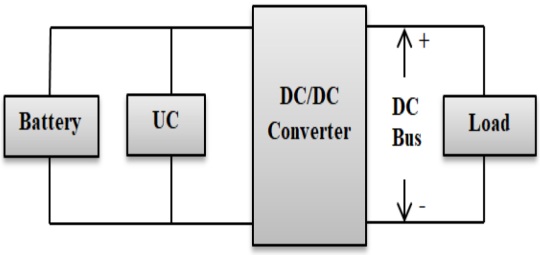
Determining the setup for hybridizing various energy sources is crucial, given the intention to utilize both the High-Speed Power Storage System (HSPSS) and the Hybrid Storage System (HSESS). There exist numerous potential configurations for hybridizing batteries and Ultracapacitors (UC), as suggested by Changle Xiang et al. (2014). The choice of configuration is influenced by factors such as the type of application.

Configurations can be broadly categorized into two types: passive configurations and active configurations.

Passive parallel arrangements involve connecting the battery with UC to DC, as shown below fig 3.



(a)Initial



(b) Second

Figure 3 Hybrid Storage System Model

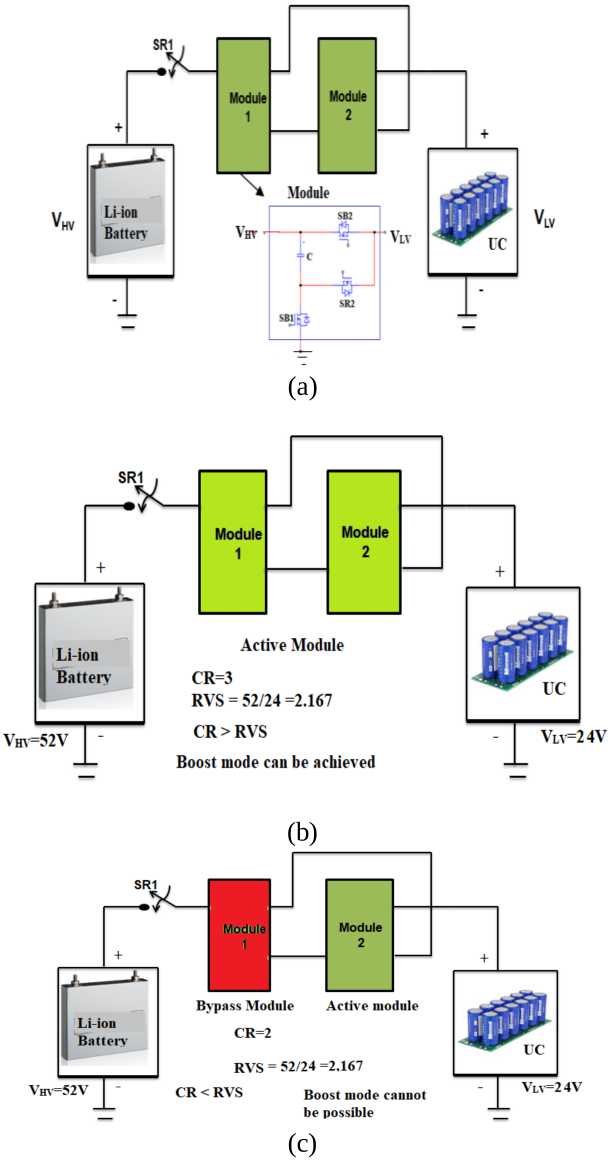
A straightforward and cost-effective parallel configuration for interfacing battery is shown in fig 4.2(a). (Hong-Wen He et al., 2010). This setup relies on the operation, which can become unpredictable over time due to aging. Consequently, this configuration lacks in control on power flow of the ESS, resulting in suboptimal uses of UC.

III. METHOD

The Conversion Ratio (CR) of the Modular Multilevel Capacitor Clamped (MMCC) converter is adjusted by manipulating the converter, a technique known as Pulse Dropping Technique (PDT) or by adding/removing modules, as discussed by Khan (2007). By varying the level of the MMCC converter through module inclusion or exclusion, redundancy features are introduced, consequently enhancing its reliability, as elaborated by Khan et al. (2009). Redundancy for any module can be attained by controlling the switching devices within the module accordingly. It's important to mention that the conversion ratio of the MMCC converter is directly impacted by the number of active modules, as emphasized by Khan and Tolbert (2009).

In the operation of the Modular Multilevel Capacitor Clamped (MMCC) converter, the modules can operate in either an active or bypass state to achieve the required Conversion Ratio (CR). The CR and Ratio of Voltage Source (RVS) are crucial factors for enabling bi-directional power flow in the MMCC converter. Specifically, the CR must exceed RVS for power flow from the Low Voltage (LV) to High Voltage (HV) side, while it must be lower than RVS for power flow from HV to LV side, as discussed by Khan et al. (2010). During the active state, a module operates normally. To transition to the bypass state, the upper arm switch of a module receives a continuous control signal while the remaining switches are kept permanently OFF. This effectively bypasses the current through the module, rendering it inactive in converter operation.

Redundancy check schematic employing two modules is shown in Fig 4 (a). When employing 2-modules, the MMCC converter functions as either a 2-level or 3-level converter. The Low Voltage (LV) and High Voltage (HV) sides of the converter usually incorporate ultracapacitors and batteries. Initially, both modules are regarded as active, leading to the MMCC operating as a 3-level converter with a Conversion Ratio (CR) of 3, as illustrated in Figure 4(b). Considering the assumed LV and HV side voltages, it is established that the Ratio of Voltage Source (RVS) is lower than CR, indicating boost operation.



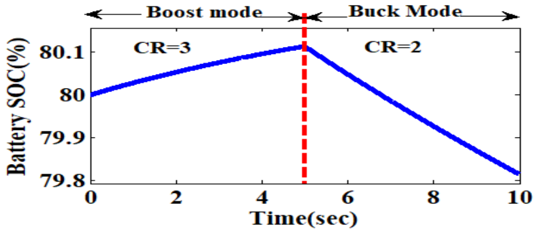
(a)

(b)

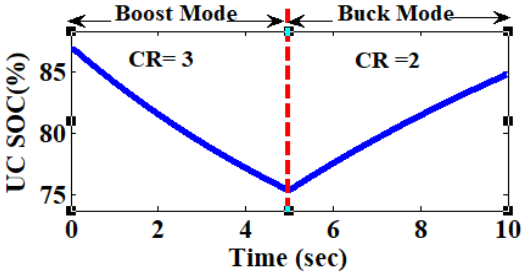
(c)

Figure 4 Redundancy check (a) MMCC converter (b) Boost operation using 2-module with CR>RVS (c) Buck operation using single module with CR<RVS

The fluctuation of the Conversion Ratio (CR) in the Modular Multilevel Capacitor Clamped (MMCC) converter, achieved through redundancy, is deduced from the State of Charge (SOC) plot of the battery and ultracapacitor (UC), as depicted in Figure 5. This observation serves as evidence that the redundancy feature inherent in MMCC enhances the reliability of the converter and endows it with fault-tolerant capabilities, as highlighted by Khan et al. (2009).



(a) Battery SOC



(b)Ultra Capacitor SOC

Figure 5: Battery and UC SOC using MMCCC

Effects of Chromium on the Stacking of Ultra-Cold Atoms (UC)

The effects of chromium on the stacking of ultra-cold atoms (UC) have garnered significant attention in the field of atomic physics and quantum mechanics. Ultra-cold atoms, often manipulated and controlled using techniques such as laser cooling and trapping, exhibit fascinating quantum behaviors at temperatures close to absolute zero. When subjected to external magnetic fields or optical lattices, these atoms can form ordered arrays known as atom lattices or optical lattices, resembling the structure of crystalline solids.

Chromium, a transition metal with unique electronic properties, offers intriguing possibilities for manipulating and controlling the behavior of ultra-cold atoms in such lattices. By introducing chromium atoms into the system or using chromium-containing compounds, researchers can influence the stacking arrangement of ultra-cold atoms in several ways.

Tuning Interactions: Chromium atoms can interact with ultra-cold atoms through magnetic or optical interactions. These interactions can be controlled and tuned using external magnetic fields or laser parameters, allowing researchers to modulate the strength and range of interactions between atoms. By adjusting these parameters, the spacing and arrangement of atoms in the lattice can be modified, leading to changes in the stacking configuration.

Creating Spin-Dependent Potentials: Chromium atoms possess nontrivial spin properties, such as magnetic moments and spin-orbit coupling. When incorporated into ultra-cold atom lattices, chromium atoms can create spin-dependent potentials that affect the motion and ordering of neighboring atoms. This spin-dependent potential can induce changes in the stacking behavior of ultra-cold atoms, leading to the formation of unique quantum phases or spin textures.

Inducing Quantum Phases: The presence of chromium atoms can induce novel quantum phases or phase transitions in the ultra-cold atom system. For example, chromium impurities may trigger the formation of spin-density waves, magnetic domains, or topological defects in the lattice structure. These emergent phenomena can dramatically alter the stacking arrangement of ultra-cold atoms and give rise to exotic quantum states with potential applications in quantum computing, simulation, and metrology.

Engineering Exotic Materials: By controlling the stacking of ultra-cold atoms in the presence of chromium, researchers can engineer exotic materials with tailored electronic and magnetic properties. By precisely arranging atoms in specific stacking configurations, it may be possible to emulate the behavior of complex materials such as high-temperature superconductors or magnetic insulators. This bottom-up approach to materials design offers insights into the fundamental physics of correlated electron systems and opens avenues for exploring new phases of matter.

IV. RESULT

The energy storage system takes up a large amount of space takes electric vehicle's powertrain (Jiya et al., 2018). When used as an energy system, a battery-alone setup significantly increases the weight of car. To address the issue of mass associated with Battery Energy Storage Systems (BESS), Hybrid Energy Storage Systems (HESS) incorporating ultracapacitors (UC) have emerged as a preferred option for EVs.

To differentiate BESS and HESS for an EV, several parameters are considered. These parameters encompass energy demand, ampere-hour (AH) battery capacity as well.

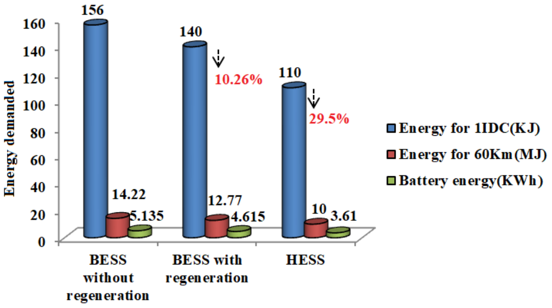


Figure 6 Requirement of EV Battery

When regeneration is not utilized, the battery capacity (HESS) is 29.63% . Consequently, for BESS, the stack current increases by 19.96%, and for HESS, it increases by 49.95%.

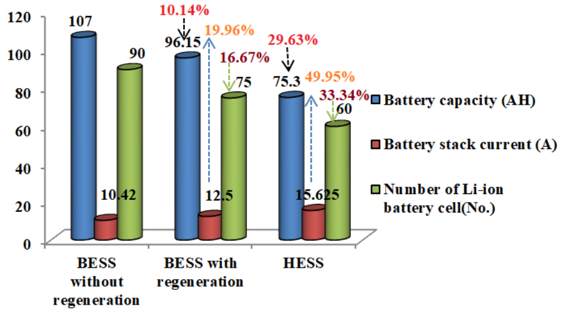


Figure 7 Basic LI-Ion Battery and ITs Requirement

The examination indicates that integrating ultracapacitors (UC) into the Hybrid Energy Storage System (HESS) decreases the requirement for five Li-ion battery cells. Moreover, the necessity for battery cells in a parallel stack decreases by 33.34%, as illustrated in Figure 6.3. Consequently, battery system are determined lower from those of both the BESS.

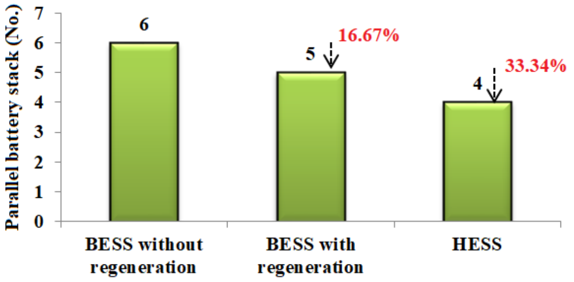


Figure 8 Different BESS Condition for Battery Parallel Stack

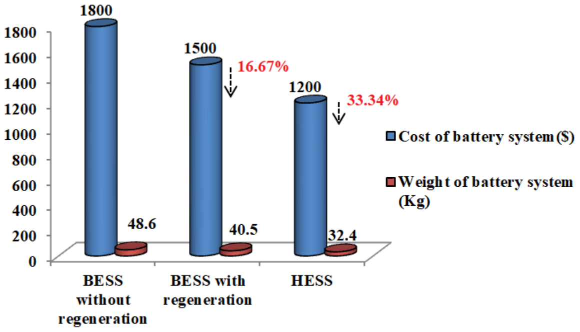


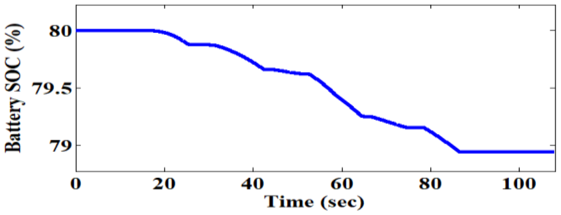
Figure 9 Battery system analysis based on Cost and Weight

Simulation of EV with and Without Energy Storage System

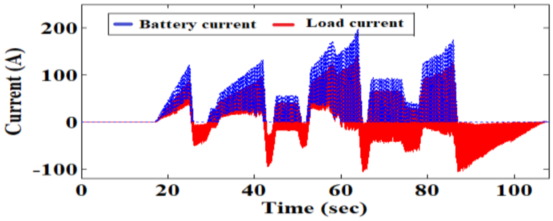
Without BESS EV Simulation

In an Integrated Drive Cycle (IDC) scenario, a lithium-ion battery as the sole, lacking regeneration capabilities. The battery operates independently, supplying power across all IDC operating modes, without receiving any regenerated power. Initially, the battery's State of Charge (SOC) is set to 80%. Figure 6.5 (a) illustrates the battery's state of charge (SOC) during IDC operation.

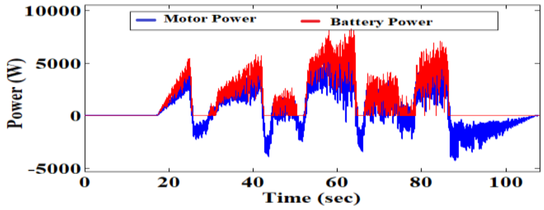
During a single IDC cycle, the battery's State of Charge (SOC) diminishes by 1%. According to the analysis depicted in Figure 10(b), the battery has the capacity to deliver up to 200A of current, resulting in a notably high Root Mean Square (RMS) current. Furthermore, Figure 10(c) illustrates the allocation of power between the battery and the motor, revealing that battery power, inclusive of system losses, surpasses motor power. As evidenced in Figure 10(d), the cumulative energy demand from the battery over the course of an IDC cycle amounts to 170KJ.



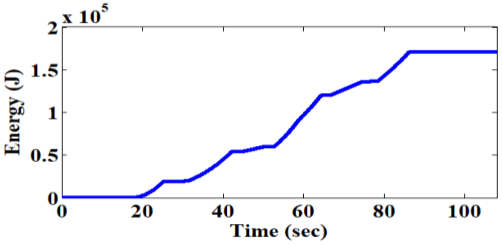
(a)Battery SOC



(b)Current



(c)Power



(d)Energy

Figure 10 Without BESS Based Analysis system

V. CONCLUSION

This paper addresses design considerations concerning the sizing of both Li-ion batteries and ultracapacitor packs for Electric Vehicles (EVs). Simulation outcomes offer valuable insights into the performance characteristics of the EV's diverse system components.

This study aims to assess the advantages of switched capacitor Luo, modular multilevel capacitor clamped (MMCC), and standard buck-boost converter topologies for electric vehicles (EVs). Through comparison, it is found that the MMCC topology surpasses others in terms of current ripple and transfer efficiency, thus justifying its selection as the interface for a semi-active configuration of battery/ultracapacitor (UC) HESS.

The filtering approach incorporates low-pass filter with an appropriate cutoff frequency to distinguish between high and low-frequency profile demand.

Modular Multilevel Capacitor Clamped (MMCC) converter is influenced by several factors, including the capacitance ultracapacitor (UC), and the associated cost. This study introduces a methodology to determine the optimal conversion efficiency of MMCC by taking these factors into account. The findings indicate that employing a 3-module, 4-EVel MMCC configuration leads to cost savings of 64.2%, a weight reduction of 10%, a 24.6% increase in ultracapacitor energy capacity, and a 50% decrease in ultracapacitor demand.

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