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Advanced Battery Management System Techniques in Electric Vehicle: A Review

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Abstract

Since they are efficient and emit no emissions when in use, electric vehicles are a key component of sustainable transportation in the modern world. The battery's performance has a big impact on the electric vehicle's driving range. The selection of the battery, its technology, and its effective use are crucial for it. As far as battery technology is concerned, lithium-ion batteries are the preferred option for power storage systems due to their superior qualities, which include large capacity, high energy density, stable power output, and effective charge/discharge performance. In day-to-day life, we are moving towards pollution-free vehicles and according to this the need for electric vehicles is rapidly increasing as a sustainable, pollution-free, and eco-friendly transportation solution. The main part of these electric vehicles is the battery management system. It is also called the nucleus of electric vehicles. In the main part of electric vehicles lies battery management system, critical components, control, and optimization of lithium-ion batteries with high capacity. This paper starts by giving a comprehensive outline of the fundamental functions of the nucleus of an electric vehicle, encompassing state of charge, state of health, and state of temperature monitoring. This review paper explores the important role of battery management system in the performance, safety, and longevity of electric vehicle batteries. This paper emphasizes the significance of data acquisition, processing, battery state, and all control algorithms within the battery management system. This paper discusses the advanced techniques of lithium-ion battery cell monitoring systems, the problems encountered in battery management systems, and their approximate solutions.

Keywords: Electric vehicles, battery management systems (EVs), lithium-ion battery, safety, charging, discharging.

INTRODUCTION

In today's world, electric vehicles (EVs)majorly play a vital character in sustainable transport due to their efficacious use and zero emission performance when in actual operation. The EV's driving range is significantly influenced by the performance of its battery. For that, the choice of battery, battery technology, and its efficient use are very important. From the current point of view for battery technology, Lithium-ion batteries are the favored choice for power storage systems because of their superior attributes, including substantial capacity, elevated energy density, robust power output, and efficient charge/discharge performance [14]. Depending on the specific use case, numerous cells are linked together in a series to create a battery chain, achieving the required voltage, which can reach up to 400 volts. For example, electric scooters are facing "drive performance issues" and they could be a great opportunity for lithium-ion batteries. EVs and e-bicycles are becoming more popular because lithium-ion batteries have a lot of advantages, like higher cell voltage and higher

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energy density. From an additional point of view, they have a much lower self-dissolve rate than nickel-based batteries, and they also don't have a memory effect. But they are not easy to overcharge, which can lead to overheating, ventilation, and even explosions. If this happens, then it is very dangerous for human beings as well as for the environment. For that, we need to monitor the voltage during charge to make sure it is very close to the full charge voltage, typically within a few percentage points. The battery management system (BMS) makes decisions based on charging and discharging rates, estimates of the state of charge (SoC) and state of health (SoH), cell voltage, temperature, and current [210].

Another crucial function of a BMS is to enhance the battery's lifespan by addressing the issue of charge imbalance. In series-connected cells, charge imbalance can occur, leading to a reduction in the battery's effective capacity, as the discharge process is constrained by the smallest. Cell, even when other cells may still contain unused energy. Li-ion batteries have very strict voltage limits, so charge unbalance can't be self-corrected, it just gets worse over time. For example, when a single cell reaches a specific voltage level, the charging process must be halted, resulting in some cells not reaching their full charge. Even when all cells possess identical capacities, any capacity mismatch is typically constrained to a few percentage points. This discrepancy can be attributed to variations in self-discharge rates or the presence of temperature gradients within a battery string. To create an EV that performs well under a range of working conditions, the BMS structure must be planned and designed. This will guarantee the safety and practical application of the management system, prevent overcharging and discharging, increase the battery's service life, and enhance the battery's overall qualities [11–13].

LITERATURE REVIEW

(1) This study presents a revolutionary solution for battery difficulties in EVs. It presents a novel BMS that segregates the battery into two sections, one dedicated to the charging process and the other designated for discharging. Renewable energy sources like solar panels and regenerative braking are used for charging. When the remaining half is discharged, the previously charged segment is utilized, and the discharged segment is reserved for the charging process. This system eliminates the need for external charging and makes the vehicle autonomous, eliminating space issues. The paper aims to analyze the system's advantages, potential applications, and capacity for solving inclination problems in EVs [1].

(2) This paper discusses battery performance prediction in EVs, focusing on lithium chemistry as the preferred energy storage technology. It examines the prerequisites and regulations governing BMSs, delineates an adaptable framework for battery management, and explores methods for estimating state-of-charge and achieving charge balance. The paper also details the development and execution of a groundbreaking BMS featuring an integrated active charge equalization component [2].

(3) A BMS is a voltaic regulator responsible for overseeing and regulating the charge and discharge processes of rechargeable batteries. It plays a vital role in electric and hybrid vehicles, as it ensures the safe and dependable operation of batteries by monitoring essential parameters, such as voltage, current, as well as internal and surrounding temperatures. The BMS carries out functions like state monitoring, charge management, and cell balancing to uphold the safety and reliability of the battery [3].

OVERVIEW

What is a Battery?

Batteries are devices that transform chemical energy into electricity. Lithium-ion is the most common type of rechargeable battery used in EVs and electronic devices, as well as e-cars.

BMS is a voltaic system used to achieve peak performance [12].

Additionally, it safeguards the battery against operating beyond its secure operational limits, keeps a watchful eye on its status, computes supplementary data, reports this data, manages its surroundings, verifies its integrity, and ensures equilibrium.

What Is an EV?

An EV is a vehicle that uses electrical energy as its primary fuel. An autonomous vehicle is an EV that does not need to be plugged into a charging station.

Lithium-Ion Battery: Properties

- High energy density.
- Low self-discharge.
- Light weight.
- High voltage.
- Long cycle life.

Features of BMS

- SoC estimation.
- Voltage monitoring.
- Current monitoring.
- SoH monitoring.
- Cell balancing.

Construction

Block diagram of BMS is shown in Figure 1.

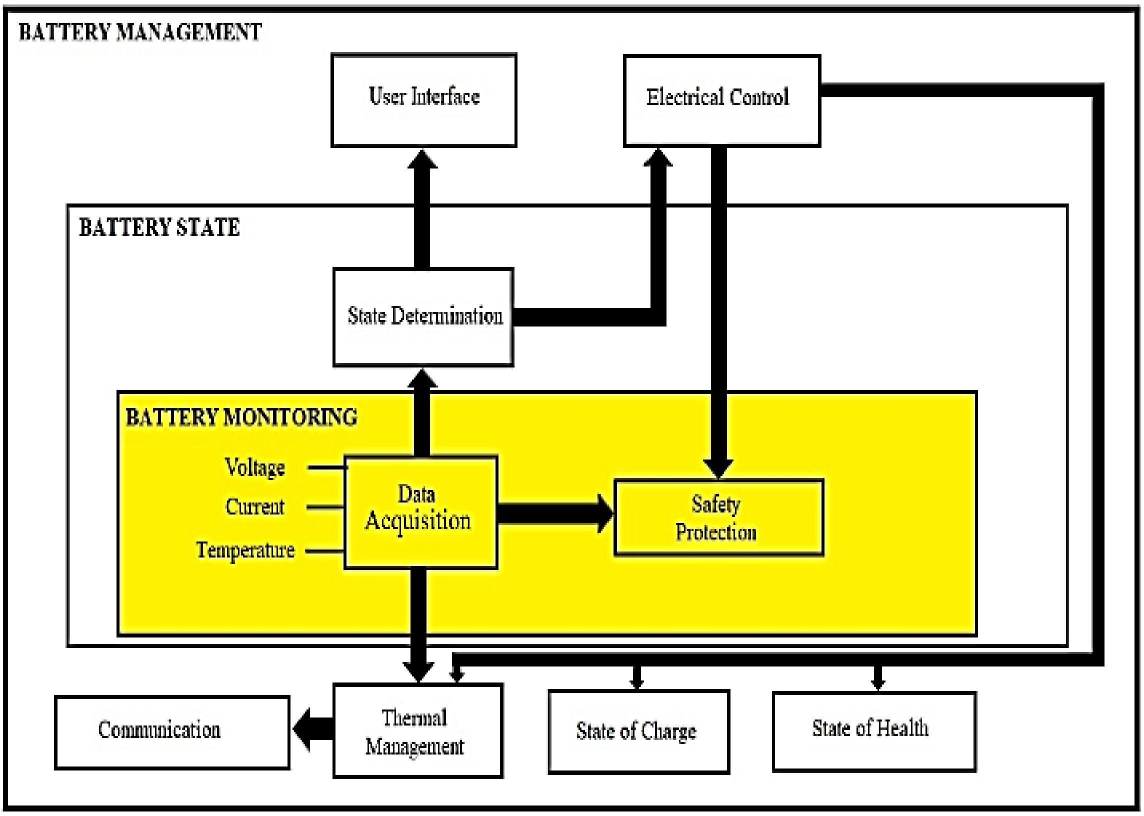

Figure 1. Block diagram of BMS.

SoC Estimation

The SoC, expressed as a percentage of the battery's rated capacity, serves as a crucial metric. It assists the BMS in assessing the battery's health and ensuring it operates safely within its designated range through the regulation of charging and discharging. Additionally, it contributes to extending the battery's lifespan [4].

SoH Estimation

The SoH estimation characterizes the battery's condition compared to that of a freshly produced battery. It provides details on how much discharging capacity is available throughout its lifespan. The capacity to cover a specific distance is described by the SoH in EVs [4].

State of Temperature Monitoring

Temperature sensors are a vital part of electric cars and are responsible for monitoring and managing several systems in the car. In severe weather, they can help avert catastrophic incidents like battery meltdowns, overheating motors, malfunctioning power components, and fires [13–16].

Methodology

A BMS monitors and controls the charging and discharging of the battery, as well as the working temperature, to maximize the optimum use of the energy within the battery and minimize the risk of damage to the battery. The functions of a BMSs are as follows (see Figure 1):

1. Data acquisition.
2. Battery status determination.
3. Electrical control.
4. Temperature control.
5. Safety protection.
6. Communication.

Several essential battery management functions, such as regulating charging and discharging, monitoring battery capacity, providing remaining usage time data, and tracking charge cycles, are required for the development of a battery-powered EV. These characteristics have an impact on the EVs' dependability and battery pack performance, but they also have an impact on the cells' cycle life, Cycle life refers to the count of charge and discharge cycles a battery, or cell can undergo under specific conditions before its accessible capacity in ampere hours (Ah) no longer meets predetermined performance criteria [16–22]. To accomplish the objective of keeping an eye on and managing the process of charging and discharging the battery as well as the operating temperature, the system comprises five primary components, which include a sophisticated, rapid-response energy management system (CASM). This CASM component is responsible for current analysis and the estimation of the cell (SoC & SoH); a voltage temperature analyzing module (VTAM) that gathers data from the DPs sampling circuits and performs additional analysis; a MOS control module that regulates the battery's turn-on and turn-off to maintain security; and a display module that shows the present electrical potential, ambient heat, (SoC & SoH), and the time remaining for the battery to the consumers, as well as a battery pack that has been divided into a few little pieces. Since hundreds of cells must be monitored, the battery pack in this BMS model was divided into smaller subpacks with fewer cells per sub-pack, making it much easier to control and monitor the cells in every sub-pack (see Figure 2). Every module within the VTAM functions autonomously, collecting data samples from the integrated circuits (ICs) within each sub-battery module. Following analysis, the information is transmitted to the CASM through the data bus. In case of an emergency, the Monitoring of State (MoS) controller is alerted via a direct channel to the microchip (MC), guaranteeing swift resolution of any anomalies [23–27]. The construction of BMS is shown in Figure 2.

When orders are provided to the Voltage and Temperature Analyzer Modules (VTAM), the ICs within the battery pack gather information regarding temperature and voltage levels as they operate are

sent to them (see Figure 2). Should the temperature or voltage of any individual cell fall outside the acceptable range, the VTAM will scrutinize the data and transmit a signal to the MOS controller. The protection circuit will then be activated by the MOS controller to keep the battery safe. Similarly, the Complex Fast-Acting Energy Management System (CASM) evaluates the SoC, SoH, and the remaining operational time by examining the current measured by the current sampling module [28].
To eliminate any threat, the MOS control will activate the protection circuit right away. Via the communication channel, each cell's voltage and temperature data are also transmitted here. Finally, each cell's character parameters will be shown on the display module. By means of the link between VTAM and the MoS controller, which monitors its status, the VTAM module instantly notifies the MoS controller in the event of an emergency, preventing any damage to the battery. Without this channel, any emergency that the VTAM module detects needs first to be forwarded to the CASM for analysis before being sent to the MoS controller. This would significantly slow down the emergency reaction time [3].

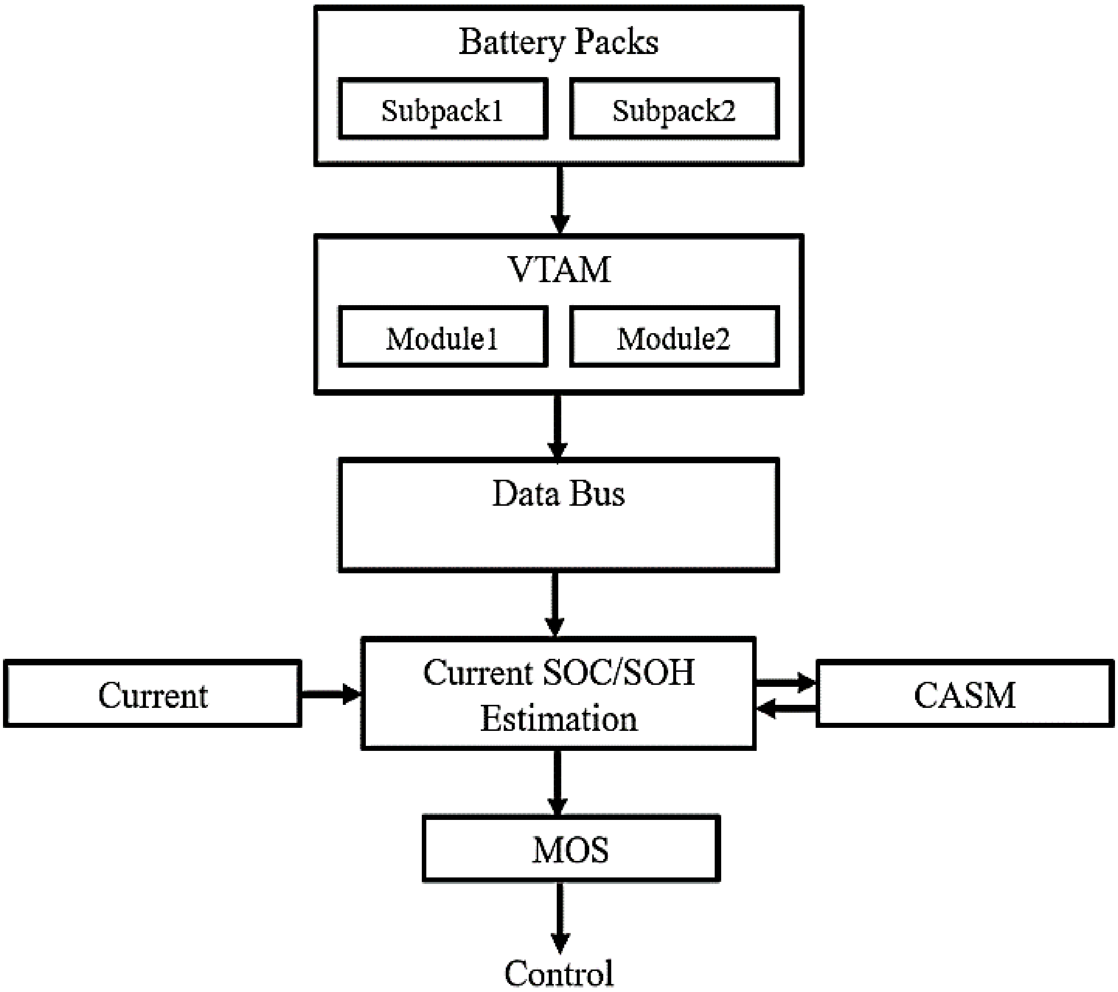

Figure 2. Construction of BMS.

Lithium-Ion Battery
Efficient use of lithium-ion battery

i. *Heat conduction:* Compared to cylindrical cells, the cell exhibits superior heat conduction due to its wide surfaces on both sides.

ii. *Packing configuration:* Compared to cylindrical cells, a smaller constructed battery is possible due to the effectiveness of cell packing. Our Li-ion battery's shape is comparable to that of prismatic Ni-Cd batteries; thus, it can be assembled using the same expertise as other batteries.

iii. *High productivity:* Because it is simple to construct the elements of the cell by winding the separators and electrodes, it has a high production. Comparing the productivity to stacked electrode-type cells, it is higher.

iv. *Possibility of a low internal short circuit:* Except in certain test scenarios, like nail penetration abuse testing, the cell has never resulted in an internal short circuit. Compared to stacked electrode-type cells, the cell has a significantly smaller "electrode edge portion" since it utilizes a single-piece positive electrode and a single-piece negative electrode.

Formation of Li-Ion Battery

A lithium-ion battery is formed through several essential procedures. First, certain compounds are coated onto metal foils to prepare the positive and negative electrodes. Copper is usually used for the negative electrode (anode), whereas aluminum is frequently utilised for the positive electrode (cathode). Concurrently, a lithium salt, either lithium carbonate (Li_2CO_3) or lithium hexafluorophosphate ($LiPF_6$), is dissolved in a solvent, usually a combination of organic solvents, to create the battery's electrolyte.

To prevent direct contact between the positive and negative electrodes, a separator – typically made of porous material – is put between them during the cell building step. The separator, negative electrode, and positive electrode are rolled or layered to create the desired shape, such as a pouch or cylindrical cell. To allow lithium ions to flow between the positive and negative electrodes during battery operation, the cell is filled with the prepared electrolyte after assembly.

The battery cell is sealed to provide both airtightness and safety. The battery experiences an initial formation charge after sealing, which is essential for maintaining its capacity and function. This procedure entails gradually charging the cell to a certain voltage. The produced battery cells are then put through a series of tests to make sure they adhere to performance and safety requirements.

The cells are placed into battery packs after passing quality control inspection. Depending on the use, these packs might have several cells connected in parallel or series. Because of their high energy density and ability to be recharged, lithium-ion batteries are widely utilized today and are vital parts of many different applications, from EVs to consumer gadgets.

Li-ion BMS

Several essential tasks are performed by the BMS, including communication, protection, balance, and monitoring. It serves as the watchful protector of the battery, monitoring cell health, continuously evaluating its condition, and enabling effective functioning. The BMS's essential parts – monitoring circuits, sensors, control algorithms, and communication interfaces – cooperate to guarantee the battery's health. In addition, the BMS balances cells using both active and passive methods to balance cell performance and prolong battery life. One of the main duties of the BMS is to monitor the voltages and temperatures of each cell. It prevents problems like thermal imbalances, over-discharging, and overcharging by carefully monitoring these factors. The BMS is a key component of safety, quickly identifying and eliminating any threats to protect the battery and its surroundings. The BMS has changed as technology has continued to advance. Artificial intelligence (AI) and machine learning have emerged because of recent developments, opening the door to predictive maintenance and the integration of cloud-based platforms and the Internet of Things (IoT) for remote monitoring and control. Energy storage and EVs have a lot of promise for the future thanks to these technological advancements, but issues with cost, size, and dependability still need to be addressed. However, the BMS continues to be a crucial part, guaranteeing the longevity, effectiveness, and safety of lithium-ion batteries in a range of applications.

Challenges/Problems in BMS

BMS are crucial to battery performance, safety, and longevity, particularly in applications, such as EVs. Some of the several challenges or problems in BMS operation and design are as follows:

i. *SoC and SoH estimation:* Estimating the level of charge and health of a battery accurately is critical for optimizing performance and maintaining battery safety. These factors, however, are difficult to measure and forecast, and errors in prediction might result in inefficient use and lower battery life [4].
ii. *Thermal management:* When batteries are being charged or discharged, they can produce a considerable quantity of heat. In addition to lowering performance, overheating can occasionally be dangerous. Battery temperatures need to be monitored and managed by the BMS to avoid overheating or overcooling.
iii. *Communication protocol:* A power management system or the vehicle's control unit are two examples of external systems with which many battery systems communicate with each other via communication networks. It's critical to guarantee a dependable and safe connection.
iv. *Data processing and algorithm:* Complex algorithms are used by BMS to process and control data. It can be difficult to develop and maintain these algorithms since they need to be precise, effective, and flexible enough to work with various battery chemistries and situations [6].
v. *Safety:* Safety is of the utmost importance, particularly in situations when battery failures might have disastrous effects, such as EV fires. To prevent dangerous situations like overvoltage, overcurrent, or short circuits, BMS must monitor several factors, including voltage, temperature, and current.
vi. *Balancing cells:* Cells in a battery pack comprising several cells (such as lithium-ion batteries) may differ in terms of their capacity or overall health. To avoid individual cells from being overcharged or over-discharged, the BMS must balance the cells to ensure that they charge and discharge uniformly, etc. [7].

Probable Solutions to the Challenges

SoC and SoH Estimation

- Use sophisticated models and algorithms to ensure precise estimation.
- Make use of extra sensors and information sources, including internal resistance measurements or impedance spectroscopy.
- For better prediction, use AI and machine learning approaches.

Thermal Management

- Create thermal prediction models to control temperature before it becomes too late.
- Use thermal insulation to keep your operating temperature at its ideal level.
- Employ cutting-edge heating and cooling techniques, such as phase-change materials or liquid cooling.

Communication Protocol

- Use CAN (Controller Area Network) or Ethernet communication technologies that are secure and standardized.
- To ensure data integrity and secrecy, use encryption, and authentication.
- Data processing and algorithm.
- Employ control systems that are adaptive to various battery types and operating situations.
- Constantly update and improve algorithms with data from the actual world and field experience.

Safety

- Include redundant circuits for protection and safety measures.
- Establish procedures for isolation and quick shutdown in the event of a failure.
- Make use of cutting-edge materials for electrical and thermal insulation.

Balancing Cells

- Make use of either active or passive cell balancing strategies to guarantee that the cell levels stay consistent.
- To reduce energy waste during balancing, use voltage-based or energy-based balancing.

Protection of EVs' Battery

Li-ion batteries, which include many series-connected battery cells in a pack, are used for energy storage systems in EVs (see Figure 2). To power the EV driving motor and systems, EV batteries can be drained and charged outside. The imbalance in voltage and charge among battery cells can occur during successive charge-discharge cycles due to changes in their physical characteristics. Factors, such as cell aging, temperature fluctuations, and manufacturing variations all play a role in creating this imbalance. Unbalanced voltage and charge profiles have the potential to compromise energy storage systems' overall longevity and performance. While undercharging could limit the cell's life and harm the battery's chemical composition, excessive charging may lead to a cell detonation. When the battery exceeds its operational limits, the BMS is empowered to halt both charging and discharging processes. Consequently, this action can lead to the battery pack failing to sustain the specified charge level necessary for its proper operation. To safeguard the battery cells, storage capacity, and operational performance of the series-connected battery pack, the charge equalization controller is crucial [3].

Future Scope of BMS

- To mitigate excessive actions that may lead to a reduction in battery lifespan, enhancing the BMS optimization algorithm is essential. This improvement should involve considering the economic and technological aspects of each cell's charging and discharging cycles, factoring in the cost associated with each cycle.
- It is possible to create algorithms that forecast the microgrid's power generation and consumption. These algorithms can be integrated with a real-time energy management approach that utilizes optimization for controlling power flow.
- The implementation of smart energy management systems, market integration, increased automation controllers, forecasting, transmission planning techniques, and visibility into renewable energy can all help grid operators overcome obstacles and avoid curtailment by providing additional transmission capacity and improved operating procedures.

Result and Discussion

Because electrical vehicles emit no pollution and are less expensive to operate than other kinds of vehicles, we transform our regular cars into them. We raise the battery's efficiency by utilizing a BMS. Two batteries are combined in the BMS to create a new battery for the cars.

CONCLUSIONS

The electric car's performance can experience significant improvement through the implementation of an advanced BMS. An essential part of electric cars that ensures battery performance that is dependable, efficient, and safe is the BMS. They also offer fixes for electric car heating, power, and inclination issues. Maintaining the BMS properly is crucial for both battery safety and dependability. The current work enhances the power performance of EVs with an emphasis on BMS research. Furthermore, the use of BMSs can significantly help to meet the goal of diminishing the release of greenhouse gases.

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