

Original Article

# Smart Battery Protection and Efficient Charging for Electric Vehicles

Amaraja Aniket Dhamangaonkar<sup>1</sup>, Ramchandra P. Hasabe<sup>2</sup>, Rishikesh More<sup>3</sup>

<sup>1,2,3</sup>Department of Electrical Engineering, Walchand College of Engineering, Sangli, Maharashtra, India

<sup>1</sup>Corresponding Author : [amarajadhamangaonkar@gmail.com](mailto:amarajadhamangaonkar@gmail.com)

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**Abstract** - In the new era of technology, Electric Vehicles (EVs) are playing an important role in sustainable transportation. However, there are some challenges in the adoption. These technologies face the problem of efficiency and safety. The proposed system gives a solution. By implementing a liquid cooling-based temperature management system, the battery system can operate within a safe operating temperature range. The autonomous charging systems use a dynamo motor to convert the vehicle's kinetic energy into electricity. A microcontroller-based system is implemented to monitor main parameters of the battery, such as cell and pack voltage, current, and temperature. A program is developed to maintain the temperature of the battery and switch between the primary and secondary batteries. For maintaining the temperature of copper tubing, liquid coolant, and a temperature sensor are used to prevent overheating, reduce the risk of hazards, and extend battery life. There are two batteries (primary & secondary) used to provide power. According to the SOC level, the charged battery is connected to the system, and the depleted battery is connected to the charger. Using autonomous charging, a dynamo motor converts a vehicle's kinetic energy to electrical energy, and it is used to charge the battery. The emergency grid charging option is included for situations when both batteries are depleted. By using a dual approach, the proposed scheme enhances safety and improves efficiency.

**Keywords** - Battery Protection, Autonomous Charging, Electric Vehicles, SOC, KERS.

## 1. Introduction

### 1.1. Background and Motivation

In the new era of transportation, the awareness of environmental degradation and the reduction in fossil fuel dependency has increased. This has accelerated the transition from conventional vehicles using internal combustion engines to electric vehicles. The electric vehicles are considered a cleaner and more sustainable mode of transportation because of their low emissions and energy-efficient operation. However, their widespread operation is restricted by challenges like battery performance, safety, and efficiency. As the battery is the core source of Electric Vehicles (EV), it must not only store and deliver power reliably but also operate safely under various environmental and load conditions [1, 2].

The main operation of a battery is to provide power for a vehicle by discharging and storing further energy by recharging. The high-rate charging and discharging operation increases heat generation-the potential risk of overheating leads to performance degradation, fires, or even explosions. Poor thermal management leads to a reduction in battery life and eventually increases the risk of failure. So, effective thermal management of batteries is now becoming a critical research focus and key motivation for advancing EV technology.

### 1.2. Batteries Used in EV

Batteries play a crucial role in the operation of an Electric Vehicle. Electric Vehicle performance, range, charging time, and overall efficiency largely depend on the battery used in the EV. So battery technology has become an important component in the electric mobility system [1, 3]. Many types of batteries are available in the market, such as Lead-Acid, Nickel-Based, Nickel-Metal Hydride, Lithium-Ion, Solid-State, High-Temperature, and Flow Batteries. Among these, Lithium-Ion Batteries are the most preferred choice for EV applications. Lithium batteries are compact and lightweight compared to other battery types. The main properties, such as low maintenance, long cycle life, and recyclability, make them ideal for sustainable modern tools. The electrical properties, such as specific energy, loading effect, charge-discharge efficiency, and high energy density, make them affordable for converter-based energy storage systems [4, 5]. In spite of all good characteristics, these batteries are sensitive to deep discharging and overcharging. So one of the key challenges in using lithium-ion batteries in EVs is thermal management. During charging and discharging, batteries generate heat, and if not properly controlled, this can lead to overheating. If the problem is left unaddressed, it leads to reduced battery lifespan or to dangerous situations such as thermal runaway or fire [1].



### 1.3. Battery Parameters

A battery has several fundamental specifications that define the working characteristics of the battery. The specifications include nominal voltage, cut-off voltage, ampere-hour capacity, C-rate, permissible operating temperature, temperature range, and allowable charge-discharge rates and cycle life. The Battery Management System (BMS) continuously measures the main battery parameters to estimate critical performance indices. The State of Charge (SOC) gives battery remaining capacity, state of Health (SOH) gives battery health condition, state of Temperature (SOT) gives battery thermal condition, and State of Power (SOP) gives useful power in the battery. These estimations enable precise monitoring, optimal control, and comprehensive protection of the battery pack throughout its operation [3, 6-8].

The SOC of a battery calculates the present capacity in comparison with its maximum capacity. It indicates the percentage of charge remaining after utilization from the highest charged state. SOC is one of the most critical indicators used for making decisions regarding battery charging and discharging. Nominal capacity of a battery refers to the total charge that can be extracted between its cut-off voltage limits. SOC estimation methods are broadly classified into three main groups: traditional, adaptive, and other advanced methods [4, 8-12].

- Traditional approaches include Coulomb counting, electrochemical modeling, equivalent circuit modeling, and open-circuit voltage estimation techniques [9].
- Adaptive methods rely on algorithms and filters. These methods include Neural Networks, Support Vector Regression (SVR), and Kalman filters. The algorithm handles noisy data, nonlinearities, and dynamic operating conditions. Other approaches include data-based techniques like Multivariate Adaptive Regression Splines (MARS) and rule-based systems like Fuzzy Logic for managing uncertainties [13-15].
- Hybrid methods combine multiple techniques. These methods include model-based approaches with machine learning or filtering methods to improve the accuracy, robustness, and adaptability of SOC calculation in real-world applications [9].

State of Health (SOH) calculation indicates the overall condition and remaining performance capability of a battery. It compares the battery condition to its condition when it was new. It is represented as a percentage, where 100% relates to the battery being in perfect condition, while 0% signifies complete deterioration. SOH is generally determined by comparing the battery's maximum available capacity with its nominal capacity. Various factors affect SOH, including capacity loss, rising internal resistance, the number of charge-discharge cycles, temperature effects, and natural aging of the battery. Estimating SOH accurately is essential for forecasting

the battery's lifespan, efficiency, and overall performance in electric vehicles. It also helps decide when the battery pack needs maintenance or replacement to ensure reliable operation. Different approaches for SOH estimation include Electrochemical [11] and Equivalent Circuit Models (ECM), and techniques that use data handling [4, 10, 16, 17].

State of Temperature (SOT) analyzes both surface and internal battery temperature. The surface temperature is measured outside the battery, while the internal temperature is usually higher and shows the true heat inside the cell. Temperature change relative to the battery directly affects the working, safety, and efficiency of the battery. The central part of the heat is generated in the core of the battery pack. Due to internal heating, the temperature distribution becomes uneven among cells. Only surface cooling can increase the temperature difference between inside and outside of the battery pack. It can cause significant degradation in the battery's health [18]. So keeping the battery temperature within a safe operating range becomes an important task. The maintenance of uniform temperature in a battery pack is challenging because it depends on the thermal management system [19]. SOT estimation considers factors like temperature differences at multiple points, battery chemistry, and real-time computational complexity. Different batteries have different thermal behaviours, so accurate estimation is needed for proper control. Methods to estimate SOT include model-based methods, direct measurement methods, and data-based algorithms [20-23].

The battery State of Power (SOP) is the maximum power it can safely deliver or absorb over a given period. SOP changes dynamically with SOC, SOH, and SOT. SOP indicates the peak power availability, helping ensure safe and efficient operation of electric vehicles. Accurate SOP estimation prevents battery damage from overcharging or over-discharging and improves overall performance [3]. The accurate SOP estimation allows the battery's power output to match vehicle demands, supporting acceleration and hill climbing. Estimation is done using battery models, real-time measurements of voltage, current, and temperature, and advanced algorithms like the Kalman Filter. The battery management system utilizes SOP values to optimize driving range and maintain battery reliability.

### 1.4. Problems in EV and Need for Innovation

Some of the key factors about EV batteries are Battery safety, charging efficiency, and infrastructure dependency. EVs carry heavy loads and also undergo variable driving conditions. The temperature sensitivity of EV batteries can cause them to perform poorly under heavy loads. The simple cooling system cannot address the issue. Hence, a reliable and safe cooling system is required to prevent the EV Battery from damage [19-20]. Another primary concern is charging efficiency. The overcharging, undercharging, and deep discharging reduce the performance of the battery. So the

problem can be addressed by accurate estimation of the SOC level and by setting the limits for charging and discharging cycles. The third problem is infrastructure dependency [5]. EV users often face long charging times and limited access to charging stations, especially in remote or underdeveloped areas. This creates difficulties during long trips or emergencies when locating a charger becomes challenging [5]. Moreover, most EVs still depend on grid electricity, which is not always generated from renewable sources. As a result, the overall operational cost of EVs can increase. These challenges reduce the convenience and usability of EVs in regions with weak charging infrastructure [24].

The existing model cannot generate power on its own under operating conditions. This increases dependency on grid power and reduces vehicle efficiency. These limitations can hinder the large-scale adoption of EVs, especially for users who travel long distances or operate in remote areas. The paper provides a solution with battery protection and autonomous charging. The practical solution involves developing a dual-battery system with kinetic energy-based autonomous charging and an intelligent thermal protection mechanism. Here, the kinetic energy of the moving vehicle is converted into electricity by a dynamo. The generated electricity charges a secondary battery. When the main battery is empty, the system automatically switches to the secondary battery to keep the vehicle running. So it recovers and reuses energy that would otherwise be wasted. Hence, the system promotes a more circular approach to energy utilization in mobility solutions. Battery safety is maintained by a liquid cooling system with copper tubing and sensors that control temperature using a microcontroller.

So, to overcome the drawbacks of existing models, the objectives of the paper are defined as:

- Implementing battery monitoring and protection using embedded systems.
- Designing and implementing a dual battery management and switching system.
- Reduce grid dependency by implementing an autonomous kinetic energy charging mechanism.
- Advanced thermal management.

## 2. Literature Review

The recent innovations show that conventional petroleum-based vehicles should be replaced by battery-operated electric vehicles. This will enhance the reduction in carbon and greenhouse gas emissions. The portable device needs an efficient energy storage device to store and supply energy to the engine. Battery technology provides a good option to fulfil this requirement. Though all techniques are adopted to make the energy storage system more efficient, the use of battery-operated EV is restricted because of accidental circumstances, health degradation, frequent battery

replacement, and infrastructure dependency. Many different types of batteries are available in the market. Many manufacturers have adopted Li-ion batteries, which are the preferred technology in electric vehicles. Li-ion batteries have lower weight, high energy storage capacity, low self-discharge, high specific power and energy, and a long lifecycle [1, 5]. This depends on the battery cell's charging and discharging properties. To estimate the exact state of the charging and discharging cycles, the state of charge, state of health, and state of function are calculated by using different techniques. For charge estimation, various methods like direct measurement, traditional techniques like coulomb counting, adaptive estimation, filter-based estimation, and model-based estimation are used. Different charging methods are adopted for better and more efficient working, like CC-CV and CT-CV charging. The classification of state of charge estimation methods depends on traditional methods, adaptive methods, learning algorithms, and other new methods like multivibrational adaptive regression splines, fuzzy logic, hybrid methods [7-9, 12-14].

The state of health of the batteries also depends on various parameters. The estimation depends on the number of cycles, temperature dependence, and internal resistance of the battery [10, 11]. Different techniques are used for SOH estimation, like capacity comparison and internal resistance calculation. For that, the new estimation techniques like equivalent circuits, neural networks, and other data-based methods are used [15-17]. The battery life also depends on the temperature variation associated with the battery. Hence, the state of battery plays an important role in battery health improvement [18-23].

As per the recent studies, it is found that, though battery technology has good performance, it has some disadvantages like short life time, fast degradation rate, and risk of getting flames. To overcome these drawbacks, the battery management system plays an important role in proper and efficient battery technology [2-4]. It protects the battery from damage and extends its life and health. The battery management requires the modelling of the cell, cell module, and battery pack, the connection of battery cells with the battery pack management system, and calculating current, voltage, and temperature of the battery pack. The different programming methods are used for optimal battery management systems for EV. These methods are adaptive dynamic programming, Support Vector Regression (SVR), and Artificial Neural Networks [5, 6]. New technologies are also being invented, like battery management systems with cybersecurity and wireless technology. The dual battery system can be implemented by using microcontroller-based base programming logic. Also, the battery setup can be charged by using a dynamo motor. It will enhance charging efficiency and decrease the grid-charging dependency [24-26]. The literature survey shows that some innovations are carried out to overcome the problem in the existing EV system. The

method of SOC estimation, Dual battery swapping, efficient cooling system, and kinetic recovery system are somewhat explored individually. The system proposed in this paper combines all objectives and innovation claims.

### 3. Block Diagram of Proposed System

The block diagram in Figure 1 represents the overall structure of a "Proposed Smart Battery Protection and Efficient Charging Device for EV".

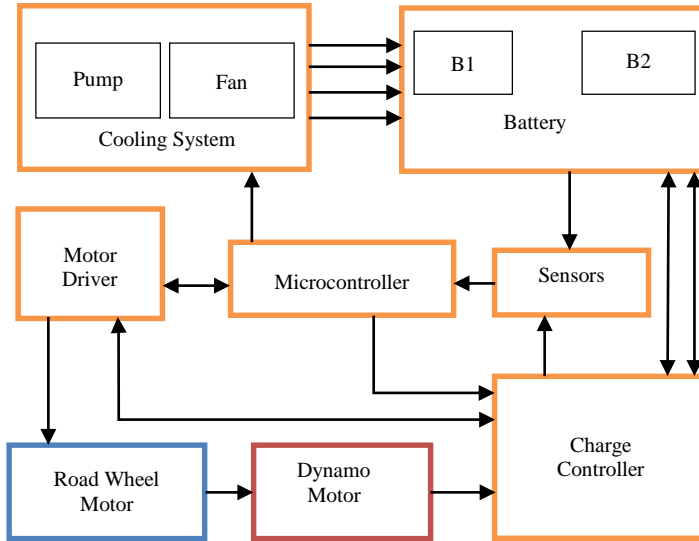


Fig. 1 Block diagram for proposed smart battery protection and efficient charging device for EV

The block-wise architecture shows a well-coordinated approach, where each component – including the dynamo motor, charge controller, batteries, sensors, and relay circuits-works together for smooth functionality. The microcontroller serves as the central unit, monitoring all parameters and controlling operations in real time. The modular design improves reliability and safety, and makes future upgrades or troubleshooting easier [24-26]. Different components are explained below:

- Road Wheel Motor: It powers the wheels of the electric vehicle and enables it to move.
- Dynamo-Motor: It is connected to the road wheel motor and captures kinetic energy generated during vehicle movement. It converts mechanical energy to electrical energy. SO it contributes to the battery charging process.
- Motor Driver: It regulates the power supply to the road wheel motor based on signals from the microcontroller. It controls motor speed and direction.
- Charge Controller: It manages the power from the dynamo-motor. The batteries (B1 and B2) are charged by avoiding overcharging. It controls the flow of electricity between the energy generation system and the battery.
- Battery (B1 and B2): These are the energy storage units for the electric vehicle. One is serving as the primary, and another is serving as the secondary battery.
- Sensors: These are used to monitor voltage, current, and temperature of the batteries. The data collected by the sensors is sent to the microcontroller.
- Microcontroller: It is the brain of the system. It processes all data collected from the sensors, and it controls various

components. The motor driver, cooling system, and charge controller are controlled by signals from the microcontroller. The controller's programming optimizes the battery charging process and protection features based on the inputs received.

- Cooling System (Pump): This subsystem helps to maintain an optimal temperature for the batteries and other critical components. The pump circulates coolant; it is controlled by the microcontroller to prevent overheating.

### 4. Simulation of the Proposed System

The simulation diagram in Figure 2 represents the overall structure of a "Smart Battery Protection and Efficient Charging System for Electric Vehicles".

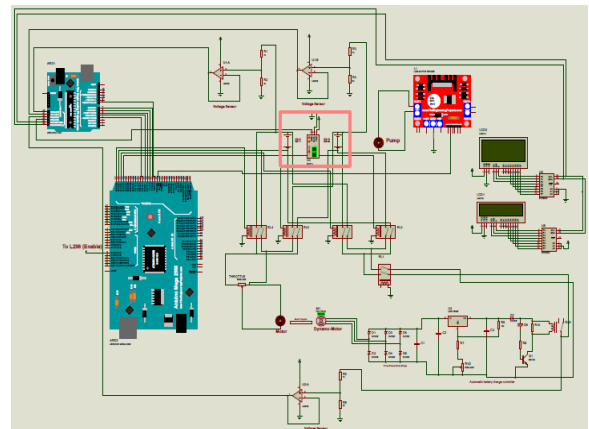


Fig. 2 Simulation for proposed smart battery protection and efficient charging device for EV

**4.1. Power Generation and Battery Switching System**

The core of the project is a self-charging mechanism using a generator (Dynamo) that outputs 18V through a mechanical coupler. It converts kinetic energy to electrical energy. This 18V output is directed towards a charging circuit built with an LM317 voltage regulator, capacitors (C1, C2), and resistors (R1, R2) to safely regulate voltage and current before reaching the secondary battery (BAT2 – 12V). The simulation also includes two batteries (BAT1 and BAT2), both 12V. The system is designed to switch from BAT1 to BAT2 once the primary battery discharges below a set threshold [26].

**4.2. Battery Temperature Monitoring and Cooling System**

A temperature sensor monitors the temperature of the battery pack. It prevents battery overheating during charging or discharging. The temperature sensor DHT11 data is given to Arduino UNO. The temperature limits are set in the programme. If the measured temperature violates the given band, the microcontroller activates the pump. Relays RL1 & RL2 are used to activate the pump and circulate the coolant through the copper pipe. Hence, rapid heat dissipation maintains battery health.

**4.3. Current and Voltage Monitoring**

The ACS712 current sensors (U6, U8, and U9) measure the real-time current flow through various parts of the circuit. The circuit current data is essential for determining load conditions, fault detection, and the efficiency of the system. The LM358 Operational amplifier is used for h amplification of signal and conditioning of the signal. The sensors convert an analog signal proportional to the measured current and provide it to the microcontroller. The display circuit is made up of LCD modules and interfaced with PCF8574 I2C converters (U3, U4). The measured parameters, like voltage, current, and temperature, are displayed to make the system more interactive.

**4.4. Central Control via Arduino UNO**

Two Arduino UNO boards (ARD1 and ARD3) are used in the simulation. It manages different segments of the system. These boards receive sensor data and execute control logic. The communication with I2C-based devices like PCF8574 ensures minimal wiring and efficient data transfer.

**5. Heat Transfer and Liquid Cooling Systems Theory**

Batteries used in EV are susceptible to temperature variations. As an electric vehicle is a high-performance energy system, the batteries undergo excessive heat generation during charging, discharging, or prolonged operation, which can damage the cells, reduce efficiency, and pose safety risks. When the battery is charged or discharged, the chemical reactions inside the tank generate heat. Along with the heat, some gases or fumes, vapours are generated as

by-products. These products, along with high temperature, increase the pressure inside the battery pack. So if the generated heat is not effectively dissipated, it leads to degradation of battery performance, reducing lifespan. In extreme cases, it causes safety hazards such as thermal runaway or explosions. Excessive battery temperature not only poses a safety risk but also increases internal resistance, which reduces the effective output of the battery.

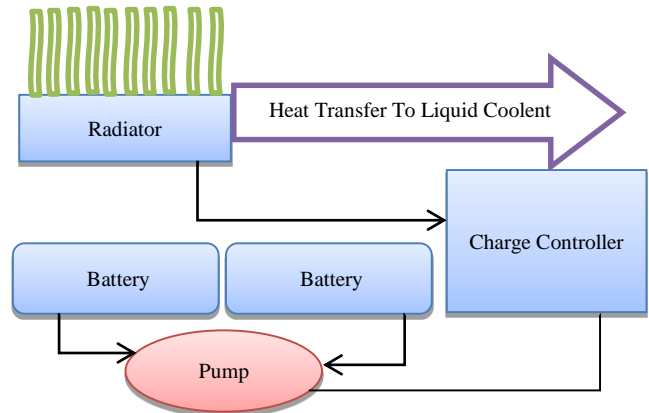


Fig. 3 Heat transfer and liquid cooling system

Hence, an effective thermal management system ensures stability and efficiency of the battery pack. Therefore, the application of a well-designed cooling system becomes essential.

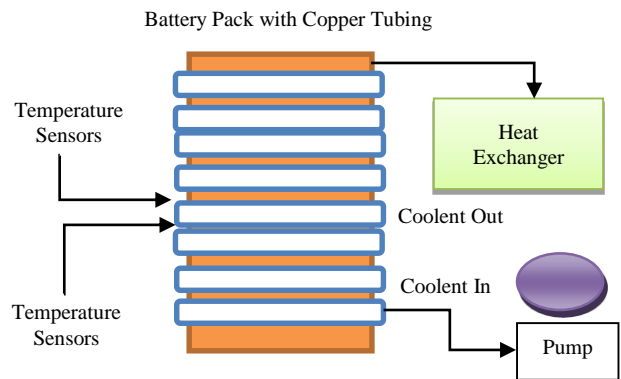


Fig. 4 EV battery thermal management

The heat transfer process begins with conduction, where heat moves from the battery cells to the copper tubing wrapped around them. The heat absorbed by the copper tubes is transferred to the coolant. The liquid coolant is circulated through tubes, so the heat is carried out by convection from the battery pack. The heat is moved towards the radiator or a region where it can safely be released to the environment. A microcontroller controls this thermal management system. The temperature sensors, like thermistors and thermocouples, are placed around the battery pack, which provide real-time temperature data to the controller. If the temperature rises above the threshold limit, the microcontroller activates the

pump. In this way, by completing the feedback loop, the system responds dynamically to real-time conditions. When the battery gets heated, the heat is absorbed by the copper pipe, as copper conducts heat very well. The coolant inside the tubes is a glycol-water mixture. If the circulated coolant cannot maintain the required temperature, the process continues till the temperature comes within the limit of about 20°C to 40°C. The heated coolant moves towards the radiator for cooling. In this way, the closed-loop system maintains thermal balance inside and outside the battery. It prevents the formation of hotspots by minimizing human intervention and ensuring precise temperature regulation.

**6. Kinetic Energy Recovery System (KERS)**

To grab wasted energy, the Kinetic Energy Recovery System (KERS) is used. The secondary battery stores the recovered energy. This can later support the vehicle or its auxiliary systems. The efficiency of EV is enhanced by KERS. It minimizes the dependence on charging stations and the power grid. The dynamo motor is connected to the wheel. The system works through the drivetrain of the vehicle. The dynamo generates electromotive force when its magnetic flux changes. It uses Faraday's law of electromagnetic induction. When the wheels turn, the dynamo's shaft rotates. It creates a movement of a magnetic field around the windings. Voltage is produced by motion, which depends on speed, magnetic strength, and coil turns. Produced energy regulates voltage & current for safe battery charging [24]. Although the recovered energy is modest compared to complete grid charging, it provides a proper backup supply. Overall, this method resembles regenerative braking systems but offers a more straightforward, more cost-effective solution.

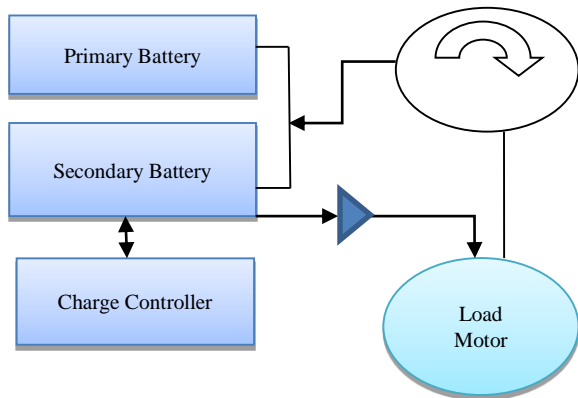


Fig. 5 Kinetic Energy Recovery System (KERS)

It provides a proper backup supply through recovered energy, and it is modest compared to complete grid charging. In all, it uses regenerative braking systems. It gives a more straightforward and more cost-effective solution. The rotational speed of the dynamo is stabilized by using a pulley-driven mechanism. The charging current supplied to the battery is managed by a microcontroller in real time. So, overall safety is achieved even at variable vehicle speeds.

**7. Dual Battery Switching and Thermal Management Theory**

In traditional single-battery setups, once the battery runs out, the vehicle must be externally charged immediately, leading to downtime and potential safety concerns if it stops during travel. To overcome these drawbacks, a dual battery system is employed. Here, the primary battery powers the vehicle, while the secondary battery is either kept on standby or recharged through energy recovery methods. The dynamo captures kinetic energy and converts it into electrical energy. So the continuous operation of battery charging is possible. It enhances convenience and reliability for users for extended trips or travel in remote areas [26].

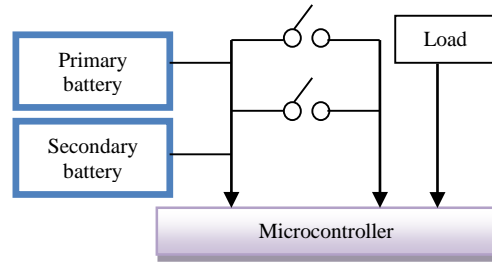


Fig. 6 Dual battery management and switching

The core principle is autonomous battery switching, controlled by a microcontroller (such as Arduino or 8051). The microcontroller continuously monitors the SOC of both batteries using voltage and current sensors. When the microcontroller detects that the voltage of the primary battery has fallen below a critical threshold-say, 10.8V in a 12V system, it triggers a switching relay mechanism. The primary battery is disconnected, and the secondary battery with a high SOC is connected. This switching process is seamless and instant, ensuring that the electric motor or load continues to receive power without any delay or drop in performance. Electromechanical relays are used due to their ability to handle higher currents safely.

**8. Battery Management System (BMS)**

A Battery Management System (BMS) is an important part of the EV battery system. It monitors various parameters and regulates the battery pack to ensure safe and efficient operation. The BMS protects against risks like overcharging, deep discharging, overheating, and short circuits. Hence, the battery performance and safety are enhanced, and it prolongs the battery's lifespan [2, 4, 6]. The microcontroller (such as an Arduino) functions as the BMS, collecting data from temperature and voltage sensors installed around the battery packs. Using programmed logic, BMS monitors battery voltage and predicts SOC. According to the SOC level, it controls the charging and swapping of the batteries. According to the SOC, programmed logic enables charging of a secondary battery with recovered energy from the dynamo and manages relay switching between primary and secondary batteries based on their charge levels. By monitoring the

temperature, it triggers the liquid cooling system. When temperatures exceed a set limit, the circulated liquid coolant cools the battery pack. This automated control allows the EV to operate seamlessly without human input.

## 9. Hardware Implementation

### 9.1. Hardware Components Used

- The hardware contains Sealed Lead-Acid (SLA) batteries, which are cost-effective, widely available, and suitable for prototyping electric vehicle systems. Although lead-acid batteries have lower energy density compared to lithium-ion, they offer reliability, ease of handling, and protection features that make them ideal for educational and experimental setups. The system includes dual lead-acid batteries, enclosed for safety, and integrated with real-time voltage and temperature monitoring. This setup supports automatic switching and regulated charging, showcasing how traditional battery technologies can still be utilized effectively in intelligent EV systems.
- A microcontroller controls the battery protection mechanism and charging logic. The process includes reading of sensor data; executing the programmed logic, and controlling the relay's action. The dynamo motor acts as a generator. It converts kinetic energy into electrical energy. When it is connected to a rotating part of the EV, like the wheel or drive shaft, then the dynamo starts to rotate to produce electricity. Hence, the charging of the secondary battery continues while the vehicle is in motion. It enables in-motion charging and reduces reliance on external charging infrastructure.
- The DHT11 is a digital sensor commonly used for measuring temperature and humidity. The sensor has a thermistor to detect temperature and a capacitive sensor to measure relative humidity, converting the analog signals into digital output. The microcontroller, such as Arduino or Raspberry Pi, uses digital output for further processing. The sensor provides data once every second using a single digital pin, which simplifies wiring but requires careful timing for accurate communication.
- A compact DC water pump is activated by the microcontroller based on temperature readings from the sensors. When the battery temperature exceeds a set limit, the microcontroller triggers the pump to start circulating coolant. The pump must be thermally and chemically resistant, especially since it runs in a hot environment and is in constant contact with fluid. It must also operate quietly and with low energy consumption to avoid draining the vehicle's central power system.
- The voltage sensors continuously measure the voltage of both the primary and secondary batteries. It provides real-time data to the microcontroller. This enables intelligent decision-making for protection, switching, and charging, unlike traditional manual checks. Each sensor measures the potential difference across a battery and transmits the

data to the controller. Since the Arduino Mega can only handle 0–5V, a voltage divider circuit reduces the 12V battery voltage to a safe input level. The sensors allow automatic switching when the primary battery voltage falls below a set limit. They also prevent overvoltage during regenerative charging by halting the process when a battery is nearly full. Overall, these sensors increase safety, reliability, and implementation of automation in the dual-battery EV system.

- A buck converter is a DC-DC power device that reduces a higher input voltage to a stable, lower output voltage. It uses Pulse-Width Modulation (PWM), where the MOSFET switch, inductor, diode, and capacitor regulate and smooth the current flow. Unlike linear regulators, it operates with high efficiency (80%–95%) and minimizes energy loss. In this project, the buck converter is used to artificially reduce the battery's State Of Charge (SOC) for testing. This controlled voltage adjustment enables quicker demonstration of automatic switching and protection features in the prototype.
- A PWM DC Motor Speed Controller module can be used to control the speed of auxiliary motors (like pumps) or even drive a small DC traction motor for a scaled-down prototype. It gives the user fine control over performance while minimizing energy loss. Its simple interface, efficiency, and wide voltage/current range make the Electronic Spices PWM controller a versatile and essential component in many motion control systems.

### 9.2. Hardware Working

For the project automation, the Arduino code is the central control system. Continuous monitoring of the battery voltage is available. Also, voltage sensors are used along with the DHT11 Sensor to monitor voltage and temperature. Automatic switching between primary and secondary batteries happens via relays, which maintain uninterrupted power. It is achieved based on set thresholds. The code written controls dynamo-based charging. It activates the liquid cooling pump. When there is a detection of high temperature, it protects the batteries. Functions are being operated in real time. There is no manual intervention. It enables a smart, self-regulated battery protection and charging system for an electric vehicle.

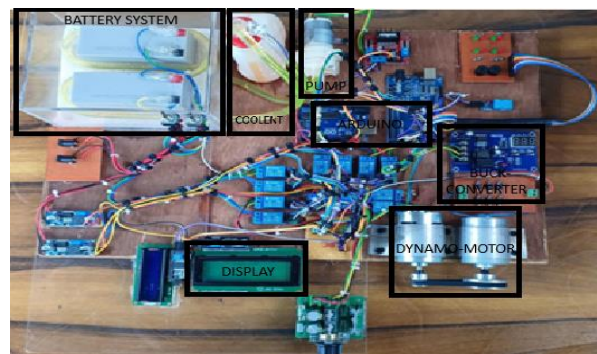


Fig. 7 Working model of the proposed smart battery protection and efficient charging device for EV

The above figure shows a complete working prototype of the Electric Vehicle battery system. The setup includes sensors, relays, a microcontroller, a dynamo, and a cooling system. The wiring is done for automated control and real-time monitoring. It demonstrates the project's real-world implementation. Two batteries are enclosed in a transparent protective casing. The casing ensures safety by preventing external damage and short circuits. A coolant pipe is also connected for thermal management. A dynamo-motor arrangement with a timing pulley and belt drive. This harnesses kinetic energy from motion to generate electricity. The display gives real-time measurements of various battery parameters.

### 10. Conclusion

The hardware results are shown in the table below. The readings are taken for battery charging and discharging. The algorithm calculates battery SOC. The battery swapping operation happens at 45% SOC, and the discharged battery is charged by a dynamo motor. Another result was obtained with temperature variation. The operation of the cooling fan is demonstrated along with the cooling condition.

Table 1. Hardware results

SOC Table for Battery 1 for Discharging		
Voltage Range (V)	SOC (%)	Battery Swapping
11.78 - 12.10	100	Battery 1 is in operation
11.72 - 11.77	95	
11.66 - 11.71	90	
11.60 - 11.65	85	
11.54 - 11.59	80	
11.48 - 11.53	75	
11.42 - 11.47	70	
11.36 - 11.41	65	
11.30 - 11.35	60	
11.24 - 11.29	55	
11.18 - 11.23	50	
11.12 - 11.17	45	Switch Operates
11.06 - 11.11	40	Battery 2 is in operation
LOW	LOW	

Temperature (°C)	Pump Speed	Cooling Condition	System Condition
35 - 45	50% of rated speed	Normal Cooling	ON
>45	Full Speed	Fast Cooling	Cut-OFF (only cooling system is in ON condition)

The proposed battery system addresses four main issues: SOC estimation, heat management, battery swapping, and recovery of kinetic energy. The hardware result shows how programmed logic monitors voltage, current, and temperature

of the battery pack. The logic also calculates the SOC of each battery, and battery swapping is achieved at a particular SOC level. This system provides equal load distribution across two batteries and an uninterrupted power supply to the EV motor. The thermal management system maintains the battery temperature while charging, discharging, and in environmental changes.

The dynamo-motor setup enables partial recovery of kinetic energy, contributing to regenerative-like energy cycles. So the proposed system enhances thermal management, prolongs battery life, and minimizes reliance on infrastructure. Overall, the autonomous charging system for EV extends driving range and battery lifespan. So it addresses the significant problems faced by EV users today.

#### 10.1. Advantages and Disadvantages

The proposed setup keeps the battery safe. It estimates battery SOC, controls charging and discharging, and protects from overheating in real time. The dual battery setup provides uninterrupted power to the EV. It also improves charging efficiency. Hence, it reduces the need for heavy charging infrastructure. The proposed system is sufficient to overcome the problems, but it has some disadvantages. It has limited power generated by a dynamo and has complex control logic. The system may have a problem during changing load conditions. However, overall, the system is cost-effective, having a scalable design and being energy efficient.

#### 10.2. Future Scope

The future scope of this project is to enhance the efficiency and safety of EV. It can also involve advanced batteries, an intelligent energy management system, and modern connectivity features. So by implementing innovative technologies, we can develop a more sustainable and user-friendly EV system.

The proposed scheme can be improved by including innovative cooling systems to protect batteries and electronic circuits from overheating. It can also be incorporated with wireless and solar-assisted charging. The design can include more compact and lightweight features. Additionally, it can feature IOT integration for remote monitoring while adhering to global EV safety standards.

#### Conflict of Interest

There is no known conflict of interest associated with the research work mentioned in the paper. The study in the paper was carried out independently. So it was not influenced by any personal, commercial, or financial aspects or relationships. There was no external organization involved at any role in the design and implementation of the proposed system. So, working, the results and conclusions presented in research work are solely based on academic and technical considerations. Hence, the publication does not involve any conflict of interest.

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