STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 13, Special Issue 1, 2025
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Review JoPC

Design and Validation of Polymer-Separated Lithium-Ion Battery Powered Mini-UPS For Networking Applications

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Abstract

Due to the growing use of semiconductor-based electronic devices in networking applications, power interruptions can cause data loss, productivity loss, and system disruptions. To eliminate these outages, Mini Uninterruptible Power Supplies are expensive and have single-use batteries with shorter battery lives. These networking wires, cables, and other electrical components are polymer-insulated. Polymers with low dielectric constants have the potential to improve antenna interlayer dielectrics, communication cables, and other hardware for high-speed wireless communication. Lithium-ion battery management systems use polyolefin separators. This study designs and validates a small, cost-effective, and efficient reusable power backup system for internet users with Wi-Fi routers, power grid monitoring security *cameras, home electronics, and emergency medical equipment. This study looks at the basic ideas behind polymer-separated lithium-ion batteries. It covers things like operation theory, circuit analysis, charging and discharging modes, and electrochemical reactions. The work examines the operation of the constant current (CC) and constant voltage (CV)-controlled DC to DC Buck Converter XL4015 model Mini-UPS, the construction, functional diagram, and operational process of the DC-DC boost converter XL6019, as well as the circuit, operational diagrams, and Schottky diode requirements of the lithium-ion battery management system (BMS-2S). The proposed method entails designing a hardware-based, hands-on, prototype rechargeable battery management system-powered Mini-UPS and analyzing its performance in real-time applications.*

Keywords: Uninterrupted power supply; lithium-ion battery; polymers; converters; battery management system; networking applications

INTRODUCTION

In the modern era of technologically advanced communication, the presence of reliable power sources is crucial for the sustained functionality of networking systems [1]. It is essential to have durable and affordable methods to mitigate the impact of power outages, given the continuous advancement and expansion of network infrastructure. Batteries are indispensable in contemporary culture due to their role in energizing a vast array of electronic devices. They are available in many sizes, ranging from little cells that provide energy for everyday gadgets to enormous systems that power electric vehicles and clean energy storage devices [2]. Lithium-ion batteries are now in high demand. iPods, personal digital assistants, mobile phones, and PCs all use lithium-ion batteries [3]. People worldwide rely on lithium-ion batteries to power their lives every day.

Polymers often possess a naturally low level of electrical conductivity, making them frequently used as materials for electrical insulation. Semiconducting polymers are a category of substances that possess the capacity to conduct electricity under certain circumstances. They

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Received Date: May 17, 2024
Accepted Date: September 13, 2024
Published Date: December 07, 2024

Citation: Raju Chintakindi, Prakash Kamisetti. Design and Validation of Polymer-Separated Lithium-Ion Battery Powered Mini-UPS for Networking Applications. Journal of Polymer & Composites. 2025; 13(Special Issue 1): S917–S933p.

consist of a lengthy sequence of repeating units that are infused with a tiny quantity of contaminants. Polythiophene (PT) is the prevailing semiconducting polymer in use. Currently, a diverse array of electrical and electronic applications use thermoplastic and thermoset polymers, together with their composites, to carry out a multitude of various purposes.

A polymer-separator refers to a permeable membrane that is positioned between the anode and cathode of a battery. The primary purpose of a separator is to maintain a distance between the two electrodes in order to avoid electrical short circuits. Additionally, the separator facilitates the movement of ionic charge carriers, which are necessary for completing the circuit when current flows through an electrochemical cell. Polyolefin is used as a separator in commercially accessible lithium-ion batteries. This material has exceptional mechanical qualities, favourable chemical stability, and is cost-effective. A polyolefin is a kind of polymer that is formed by the polymerization of olefin ethylene. The Li-ion separator must have permeability, and the pore size must fall within the range of 30 to 100nm. The optimal porosity range is 30–50 percent. This container has a sufficient amount of liquid electrolyte and allows the pores to seal shut in the event that the cell gets too hot [4].

The proposed Mini-UPS (Uninterruptible Power Supply) for WiFi routers is a small and efficient device that offers backup power to your WiFi router in the event of a power failure or disruption [5]. Regarding the choice of router box materials, both Poly Vinyl Chloride and Acrylonitrile Butadiene Styrene would be suitable. Steer clear of UV-resistant polymer variations since they usually include a carbon filler obstructing the Giga Hz signal. It functions as a secondary power source, guaranteeing continuous internet connectivity in the event of a power outage. Contrary to conventional UPS systems, which are large and costly, a Mini-UPS is particularly designed for WiFi routers and is far smaller and more cost-effective.

This portable, lightweight option can be quickly linked to the router to provide energy backup. When the primary power source is accessible, the Mini-UPS for WiFi router recharges its integrated battery. During a power loss, the Mini-UPS promptly transitions to battery power, ensuring uninterrupted operation of your WiFi router. High-performance polymer materials with both low dielectric constant and low dielectric loss have found extensive use in high-speed communication networks [6]. Hence, polymers with a low dielectric constant hold promise as attractive materials for high-speed wireless communication applications, including antenna interlayer dielectrics, communication cables, and other communications hardware [7]. This guarantees uninterrupted internet connectivity, even in the event of long-lasting power failures. Communication infrastructure often necessitates compact dimensions, lightweight construction, minimal energy consumption, and mobility. Flexible polymer materials provide practical use in the fabrication of communication devices [8].

An important benefit of using a Mini-UPS for a WiFi router is its user-friendly nature. This gadget is a plug-and-play device that only takes a minimum amount of setup. To initiate backup power, just establish a connection between the Mini-UPS and your WiFi network using the wires supplied. Durable industrial wirings and cables are created using various polymer compounds, such as thermoplastic polyurethane solution-based formulations. In addition, polyvinyl chloride (PVC) and ethylene-vinyl acetate (EVA) are used as low voltage copper conductors in solar energy applications [9]. When selecting a Mini-UPS for the WiFi router, it is crucial to take into account elements like power capacity, compatibility with your router's power needs, battery longevity, etc. Polyaniline (PANI) is a polymer with excellent electrical conductivity. It is often used in the production of electronic devices, including sensors, batteries, and capacitors [10]. Choosing a Mini-UPS that aligns with the power capacity of the router is essential for achieving maximum performance and preventing any harm [5].

A detailed study of existing UPS systems, battery advances, and networking setup requirements will emphasize crucial design and limits. The proposed Mini-UPS system that balances cost, energy efficiency, and reliability will ensue. In-depth experiments, comparative investigations, and performance evaluations will establish the UPS system's efficacy in different networking settings.

The DC-DC Buck converter, specifically the XL4015 model, is capable of supplying power to devices that need moderate to somewhat high loads, up to its maximum output current of 5A [11]. With efficiency ratings that often surpass 90%, this converter ensures that there is little power loss throughout the voltage conversion process. The XL4015 module is a commonly used component in power supply units, battery charging circuits, and other electronics projects. Its reliable performance and small size make it a favorite among experts, engineers, and enthusiasts looking for stable and effective voltage control solutions [12]. Experts favor its broad popularity across several electronic projects and applications due to its dependability, simplicity of usage, and flexibility.

The goal of the present research is to revolutionize the uninterruptible power supply (UPS) market for networking applications in an attempt to meet this urgent requirement. The primary objective is to conceptualize, develop, and thoroughly analyze a Mini-UPS system with interchangeable batteries that is both affordable and highly efficient for networking configurations. This proposed prototyping experimental work can give a solution to sudden power failure problems, especially for light-weighted and simple circuits, by minimizing cost barriers and maximizing energy utilization by combining innovative design principles with demanding analysis practices. The proposed Mini-UPS system is a small and compact device that allows for easy integration into networking configurations. This provides a consistent and dependable power supply that strengthens the foundation of interlinked digital communities.

Section II covers the fundamental concepts of the polymer-separated lithium-ion battery, including a circuit analysis of the rechargeable battery structure, charging and discharging modes of operation, the creation of electrochemical reactions, and operation theory methods. Section III covers the different converters design and components like a constant current (CC) and constant voltage (CV)-controlled DC to DC Buck Converter XL4015 model Mini-UPS operation and the DC-DC boost converter XL6019 structure, functional diagram, and operational procedure for Mini-UPS functioning. Section IV presents a circuit diagram and an operational diagram of the lithium-ion battery management system (BMS-2S) and the need for a Schottky diode. Section V presents the experiment's results and validation of a reusable battery-powered Mini-UPS for networking applications. Section VI covers the test results, overall conclusions, and future scope.

THE FUNDAMENTAL DESIGN AND OPERATION OF A POLYMER SEPARATED LITHIUM-ION BATTERY

Portable devices, electric cars, and clean energy storage equipment commonly use lithium-ion batteries, which have a worldwide market growth rate of 8.5% [13]. Although they have achieved success, further advancements are needed to improve the features and characteristics of their various components, namely electrodes, separators, and electrolytes. These portable batteries have gained wide usage due to their extended life cycle, low weight, and great energy density compared to conventional rechargeable battery packs. The 18650 lithium-ion battery is a rechargeable battery that consists of cells where lithium ions go from the anode to the cathode via an electrolyte during discharge and reverse during charging.

The polymers used in 18650 Li-ion batteries are as follows: Poly vinylidene difluoride (PVDF) is a polymer that serves as a binder and adhesive for electrodes in these batteries. These batteries use polyethylene oxide (PEO) as a polymer electrolyte. It is renowned for its exceptional ionic conductivity and durability. Polyacrylonitrile (PAN) is a polymer that serves as a binder and adhesive for electrodes. Polymethyl methacrylate (PMMA) is a polymer that serves as a binder and adhesive for electrodes in 18650 lithium-ion batteries. Polymers are essential for the proper functioning and performance of 18650 lithium-ion batteries. They allow for efficient charge and discharge cycles while also ensuring the battery's overall safety. Separators play a crucial role in liquid electrolyte batteries. A separator typically comprises a polymeric membrane that creates a layer with micropores. In relation to the electrolyte and electrode materials, the material must exhibit chemical and electrochemical stability, and it must also possess sufficient mechanical strength to withstand the high stress during battery assembly. Fig. 1 depicts the schematic illustration of a battery, which includes a polymer separator. The structure and features of batteries significantly impact their performance, including energy and power densities, cycle life, and safety [14].

Lithium-ion Rechargeable Battery Structure

A rechargeable lithium-ion battery consists of one or more cells, which are power-generating units. [16]. There are three parts to every cell: the electrolyte, the negative electrode, and the positive electrode. The positive, or +, end of the battery connects to a positive electrode. The negative, or −, terminal is connected to a negative electrode, and between them is an element known as an electrolyte. A chemical substance, such as lithium-cobalt oxide (L_iCoO_2) or lithium iron phosphate $LiFePO_4$, creates the positive electrode [17]. The negative electrode typically consists of graphite, or carbon, as illustrated in Figure 2 [18]. The separator is positioned between the electrodes and functions as the conduit for the movement of lithium ions during the charging and discharging operations. The mechanical characteristics of the separators are a topic of significant study focus due to their influence on battery performance, assembly, and stability.

The electrical characteristics, namely the dielectric constant and ionic conductivity, of the polymer matrix play a crucial role in facilitating the ionization of lithium salts and enhancing their diffusion [19].

Lithium-ion Rechargeable Battery Operation

The fundamental operation of lithium-ion batteries relies on the movement of lithium ions between the cathode (positive electrode) and anode (negative electrode). During the process of discharging, lithium ions move through an electrolyte solution from the anode to the cathode, generating an electric current that provides power to various devices. During the recharging cycle, lithium ions go in the reverse direction, namely from the cathode to the anode. Generally, graphite is used as the anode, while lithium metal oxide is used as the cathode. Frequently, the electrolyte consists of a dissolved lithium salt in a solvent, which aids in the movement of ions. The function of separator materials is to allow the movement of lithium ions while preventing any physical contact between the cathode and anode to prevent short circuits [20].

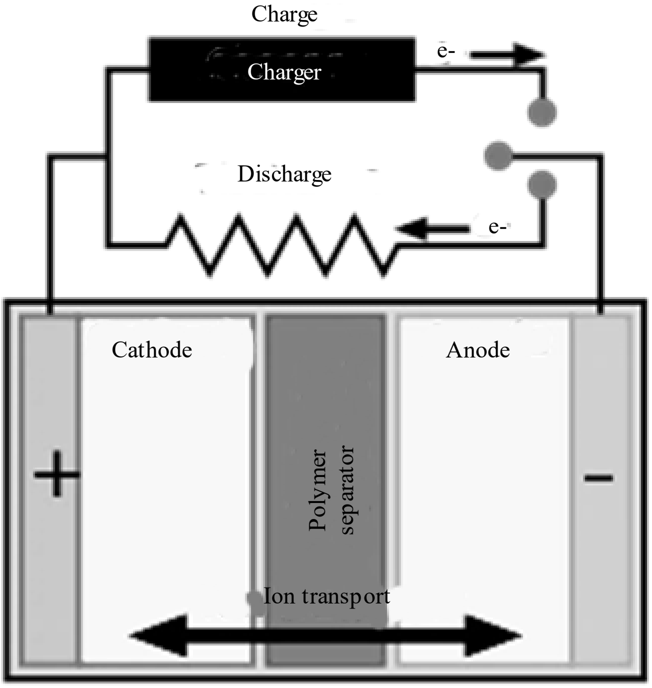

Figure 1. Schematic representation of a battery including a polymer separator [15].

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

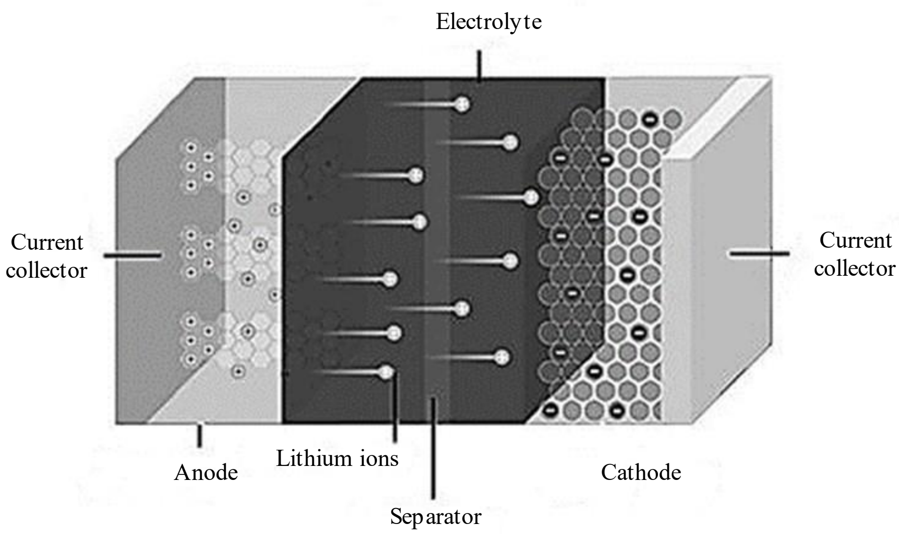

Figure 2. Structure of lithium-ion rechargeable batteries [18].

The movement of lithium ions through the electrolyte between the anode and cathode provides the energy for a lithium-ion battery. During the charging process, an applied voltage causes the migration of electrons from the power source to the battery. The electrolyte facilitates the movement of lithium ions to the anode, where they are stored as lithium intercalation compounds. The cathode simultaneously releases lithium ions, which then move through the electrolyte towards the anode, generating an electrical current that can power other objects or automobiles. During the process of discharging, the electrolyte facilitates the movement of lithium ions from the anode to the cathode, generating an electric current that may be used to operate devices or vehicles. After the completion of the charging and discharging procedure, when the battery's capacity is all used up, it has to be recharged [21].

A process of electron flow originates between the anode and cathode due to the anode's release of lithium ions during the battery's discharge and supply of electric current. When the device is connected, the anode absorbs the lithium ions that are released by the cathode, which then triggers the reverse process. The battery's energy density and power density are its most prominent characteristics. Battery energy density is a measure of the amount of energy that a battery can store relative to its size, often given in watt-hours per kilogram (Wh/Kg) Power density, quantified as the ratio of watts per kilogram (W/kg), indicates the amount of electrical energy stored in a battery about its weight. Fig. 3 shows the current modes of operating cycles for charging and discharging.

The raw material composition of various lithium-ion battery types varies. Higher-end batteries incorporate nickel and manganese in variable ratios, whereas all common lithium-ion battery types include 11% lithium and varying levels of cobalt [21].

CONVERTER FOR MINI-UPS

DC-DC Buck Converter

Choppers are another name for DC-DC converters. The step-down chopper, also known as the Buck converter, is a device that lowers an input DC voltage to a designated DC output value [23]. The DC to DC Buck Converter Module is designed to provide constant current (CC) and constant voltage (CV) control. The XL4015 converter is a highly regarded DC-DC Buck converter module that is renowned for its versatility and efficiency in reducing voltage levels. It is a Buck DC to DC Converter, 5A, 180 KHz, and 36V. This module's sturdy design and ability to effectively control greater input voltages to desired lower output voltages make it a popular option for a variety of electronics applications [24]. With its large input voltage range (usually 4V to 38V), the XL4015 can handle a wide variety of power sources with reliability, meeting a wide range of project needs. Its included potentiometer allows for exact control of the output voltage, making it suitable for a variety of devices and situations [25]. Interfaces, enclosures, electrical wiring, and cabling all use high-performance polymers. The mechanical properties range from very flexible to extremely rigid. These polymers must possess the capacity to withstand temperatures above 200°C [26]. Even when used in thin walls, the materials must exhibit flame-retardant properties and be resistant to arcing and tracking. As a result, makers often use it in the manufacturing process of electrical connections and switches. The material is a polymer synthesized from phenol and formaldehyde. Bakelite is the substance used in the production of electrical switches. Thermosetting plastic is a kind of polymer that can withstand high temperatures with o (mendeley)out experiencing any changes in shape or structure. Furthermore, it has exceptional insulating characteristics and demonstrates little heat conduction. Consequently, producers often use it in the fabrication of electrical connections and switches. The material is a polymer formed by the combination of phenol and formaldehyde [1].

Figure 4 displays two multi-turn trim pots that may be used to adjust the output voltage and output current. These trim pots are separate from the fixed terminal connections for both the input and output. In addition, there are three LED indicators: the constant-current (cc) symbol is positioned next to the input connector, while the battery charging and battery full indicators are the subsequent two LEDs, mostly used for battery charging purposes. An incessant voltage (CV) and incessant current (CC) converter may be exceedingly advantageous in a multitude of circumstances. For example, this module facilitates the process of charging a lithium battery at a consistent rate of electric flow [27].

LED devices primarily use Polyphenylene Vinylene (PPV) as their primary polymer. With a band gap of around 2.5 electron volts, this material has the ability to produce light in the yellow-green spectrum. Polymer light-emitting diodes (PLEDs), a very promising technology for displaying real-time data, have attracted considerable attention from several research firms. These devices are very compatible with many types of displays because to their ease of processing and ability to give mechanical flexibility. Seven-segment displays can utilize different technologies to produce or regulate light for each segment, such as liquid crystal displays (LCDs), light-emitting diodes (LEDs), electrochromic displays, cold cathode gas discharge (Panaplex), vacuum fluorescent (VFD), incandescent filaments (Numitron), and other technologies [29]. Polymer indicators are self-contained polymers that provide an optical response indicating a certain exposure over time.

The XL4015, a 180 KHz constant-frequency pulse width modulation in Buck (step-down) DC to DC conversion device, is capable of driving a 5A load with excellent line and load control, minimal ripple, and high efficiency. This easy-to-use regulator includes a fixed-frequency oscillator and intrinsic frequency correction, requiring only a few additional elements. Figure 5 illustrates the circuit structure of the Buck converter [30].

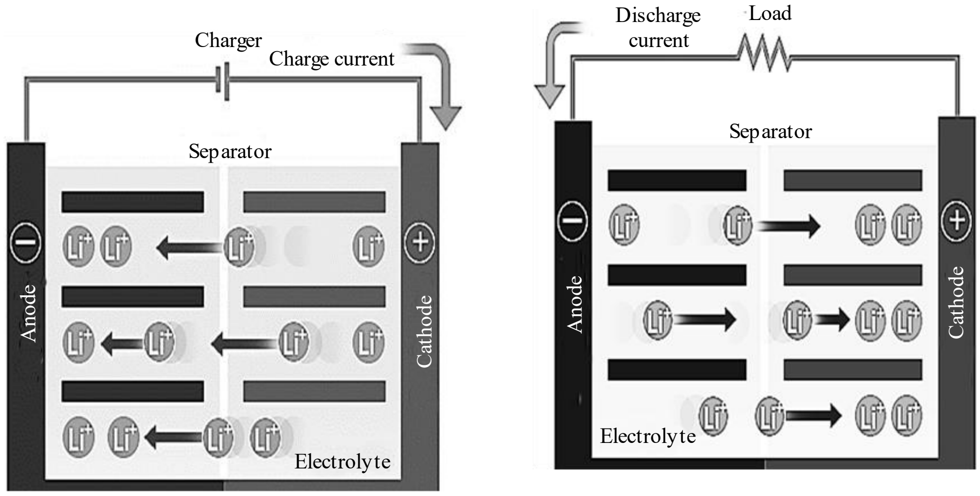

Figure 3. Charging and discharging modes of operation [22].

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

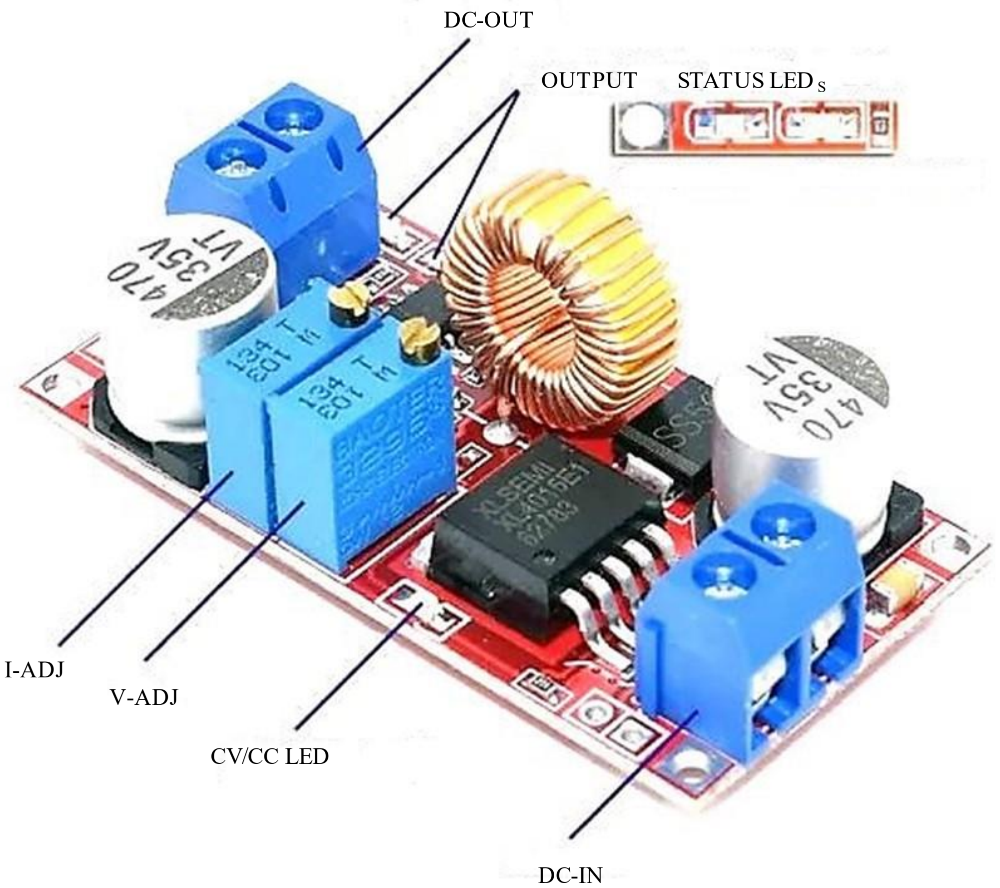

Figure 4. Structures of the DC-DC Buck Converter Module include constant voltage (CV) and constant current (CC) [28].

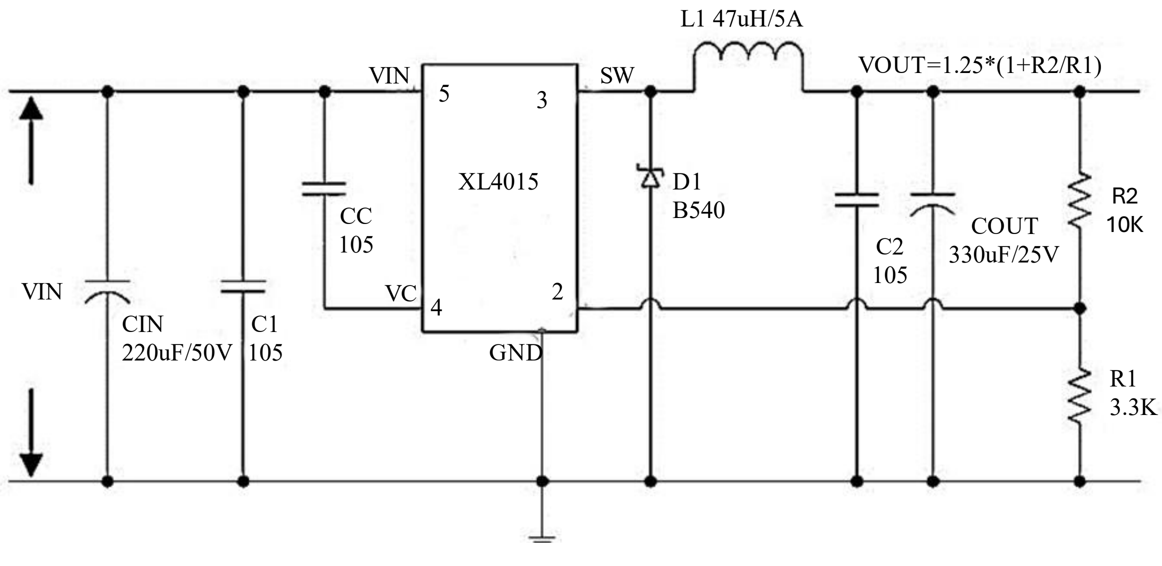

Figure 5. The buck converter (XL4015) circuit diagram [31].

The first connector connects to the DC input of an unregulated power supply. Modify the constant voltage and current levels using the following 10K potentiometers. Additionally, the board includes three light bulbs. The first one, which is located next to the input connection, indicates whether the module is operating in constant-current mode. These two indicators, located close to the output, primarily serve battery charging applications [32]. Apart from that, the device's output voltage ranges from 1.25V to 32V, while the integrated input voltage ranges from 8V to 36V. The device's PWM may achieve 100% duty cycle and 180 kHz operating frequency when it is running at maximum load. The module has a constant output current of 5A and a working efficiency of up to 96%. In terms of safety characteristics, it provides current limit functionality, short circuit protection, and thermal cut-off [31].

Begin by establishing a connection between the Buck converter module and the power supply. Subsequently, connect the output of the module to a DC load, following the functional diagram shown in Figure 6. As per the test, the circuit is using a continuous load of 1A. Considering the module's modest size and its ability to provide a steady 5A current, the XL4051 is a highly cost-effective and robust module for battery charging and projects. The XL4015 is a widely utilized integrated circuit for Buck (step-down) DC-DC conversion in electrical devices, effectively controlling voltage. Each of the many interrelated parts that make up its function block is essential to the conversion process [3].

The voltage reference is the primary component of the XL4015. This determines the converter's desired output voltage level. It serves as a reliable benchmark for comparing the actual output voltage. An error amplifier compares the output from the voltage reference with the actual output voltage. This part produces an error signal by amplifying any voltage differential between the intended and actual values. This signal provides an essential indication for modifying the output voltage [34].

The Pulse Width Modulation (PWM) comparator compares the amplifier's error signal with either a reference signal or a sawtooth waveform. The comparison produces a pulse-width modulated signal that controls the converter's switching behavior. Then, the PWM signal supplies a driving circuit. This circuit is in charge of managing the power MOSFET's (Metal-Oxide-Semiconductor Field-Effect Transistor) switching behavior. It modifies the MOSFET to control the current flow, which in turn modifies the output voltage. In the converter, the MOSFET functions as the main switch. Activating the MOSFET allows current to flow from the input to the output, transferring energy. When turned off, it stops the flow of current. In the converter circuit, the MOSFET typically connects to an inductor and a capacitor. During the MOSFET's conduction phase, the inductor stores energy, while the capacitor smooths the output voltage to lessen ripples and fluctuations. Frequently, the XL4015 comes with a feedback network. The error amplifier receives information from this network that it detects about the output voltage. This feedback loop continuously monitors and adjusts the output voltage to ensure it is at the appropriate level. When combined, these parts trigger a controlled step-down conversion process. The voltage reference establishes the goal, the error amplifier detects differences, the PWM comparator generates the control signal, and the MOSFET regulates the output voltage in coordination with supporting components [35]. The integrated mechanism of the XL4015 provides effective and consistent voltage control. This makes it a top option for a variety of electrical systems where accurate and regulated power conversion is crucial.

The control board insulating materials like fiberglass or plastic often compose Printed Circuit Board (PCB) providing mechanical support, electrical connection, and insulation. PCB substrates often use materials such as a glass-reinforced epoxy laminate (FR-4), which is a composite made of epoxy resin and fiberglass, as well as polyimide [36]. Polyimides are a kind of polymer that consists of imide monomers. This diverse collection of polymers includes a broad range of chemicals, including both natural and synthetic molecules. PCBs use Polytetrafluoroethylene (PTFE), sometimes known as Teflon, as a high-performance polymer due to its outstanding electrical properties and low dielectric constant.

DC-DC Boost Converter

A high-performance, multipurpose step-up (boost) DC-DC converter, the XL6019 provides effective power control for a range of electronic applications. This module is renowned for its wide input voltage range, often spanning from 5V to 32V. It also has the impressive stability to smoothly raise lower voltages to higher ones. With an output voltage range of 5V to 35V, customers may accommodate a wide range of power needs thanks to this functionality. The XL6019's switch current limit, frequency adjust, and shutdown mode provide ideal control and protection methods, boosting the device's dependability and safety while in use. With an efficiency that often approaches 94%, this module demonstrates its ability to control power transmission with little energy loss, which makes it a desirable option for applications that need low power consumption. The XL6019 regulator is a current mode, broad input range DC/DC converter that may produce either positive or negative output voltages, as shown in Fig. 7. It has four configuration options: boost, fly back, SEPIC, and inverting. The XL6019 achieves stable functioning across a broad range of supply and output voltages through its integrated N-channel power MOSFET, constant-frequency oscillator, and current-mode design. The XL6019 regulator is particularly designed for use in portable electronic devices [37].

The DC-to-DC step-up module utilizes the XL-Semi XL-6019, offering a maximum switching current of 5A and a conversion efficiency of up to 97%. The XL6019 boost converter module has two input pins for VCC and GND located on its left side. There are two output pins located on the right side of the module. To get the desired output voltage, it is necessary to adjust the trim-pot screw. The feedback resistance value is modified in response to the input voltage, which in turn affects the output voltage. The output current of this module is consistently lower than the input current due to its operation as a step-up converter. For output powers above 10W, it is necessary to include a heat sink with the module in order to avoid any damage [38].

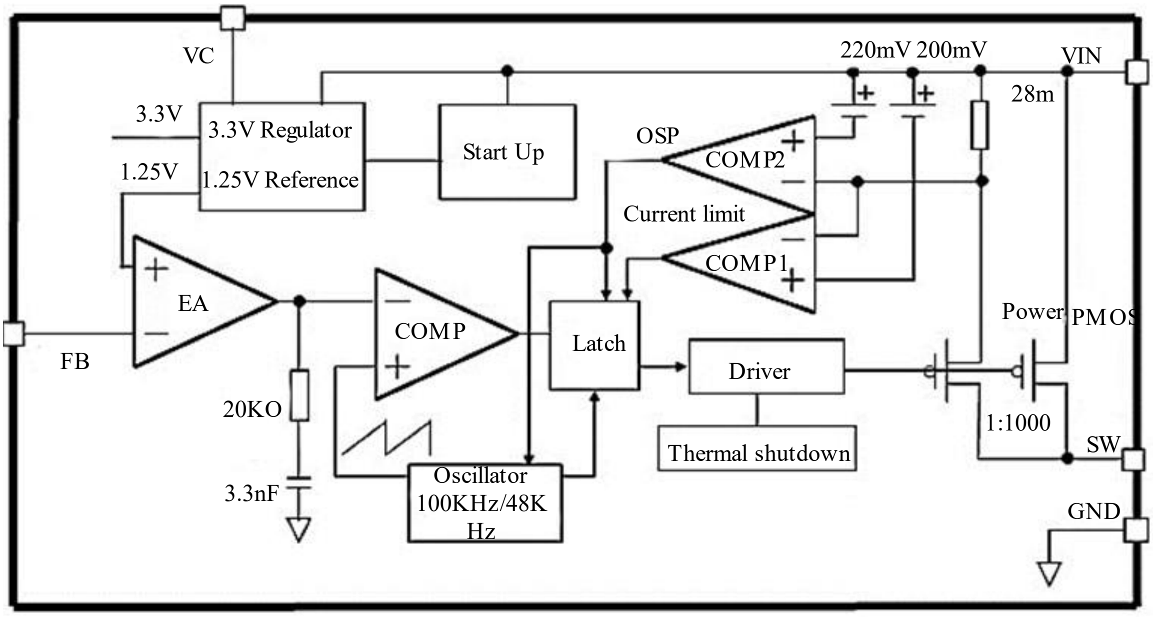

Figure 6. The buck converter's functioning schematic, XL4015 5A [33].

Figure 7. Structures of the DC-DC boost converter (XL6019) module [38].

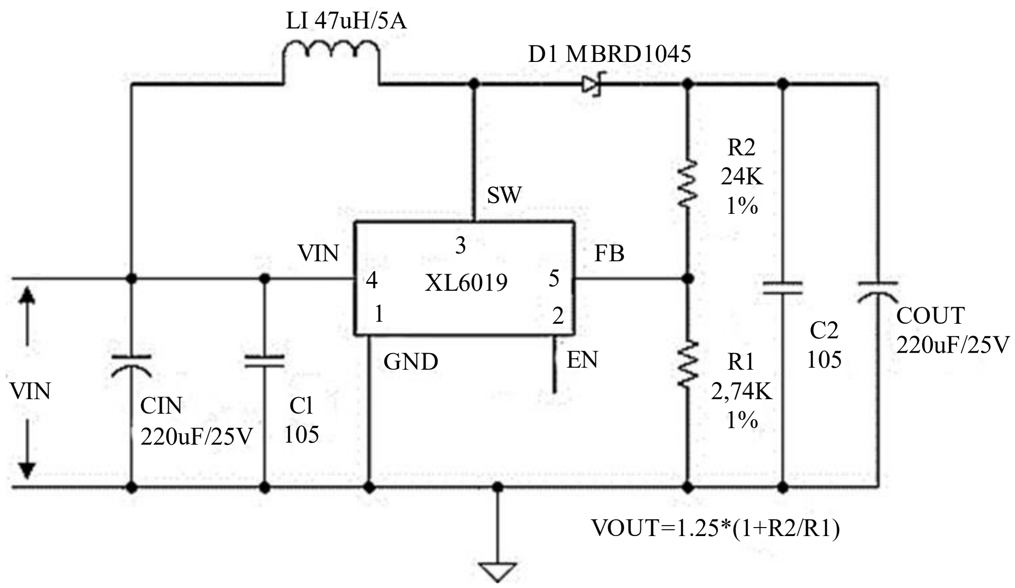

Figure 8. The boost converter (XL6019) operational circuit diagram [39].

A common non-isolated power stage architecture that goes by the name "boost" or "step-up power stage" because the needed output voltage is always greater than the input voltage, has the same polarity, and is not isolated from the input is what power supply designers choose for the boost power stage. Figure 8 shows the boost converter (XL6019) operational circuit diagram. The device exhibits exceptional reliability due to the inclusion of a comprehensive reliability protection circuit, integrated thermal protection, and over-current protection. An efficient thermal design enables the system to achieve a conversion efficiency of 90% or more. The TO263-5 package is suitable for booster applications with a power output of up to 30 W [30].

High reliability, a complete reliability protection circuit, integrated thermal protection, and over-current protection. Convenient thermal design allows for system conversion efficiency to reach 90% and beyond [30]. This DC-DC boost converter, the XL6019, uses a function block diagram as shown in Figure 9. Knowing this diagram makes it easier to understand the important parts and how they work together in the XL6019 module. The reliability of the over-current and thermal safety mechanisms that are seamlessly integrated. A broad input voltage range with a maximum input voltage of 35 volts. The maximum supported voltage is 40 volts, with an adjustable output voltage [40].

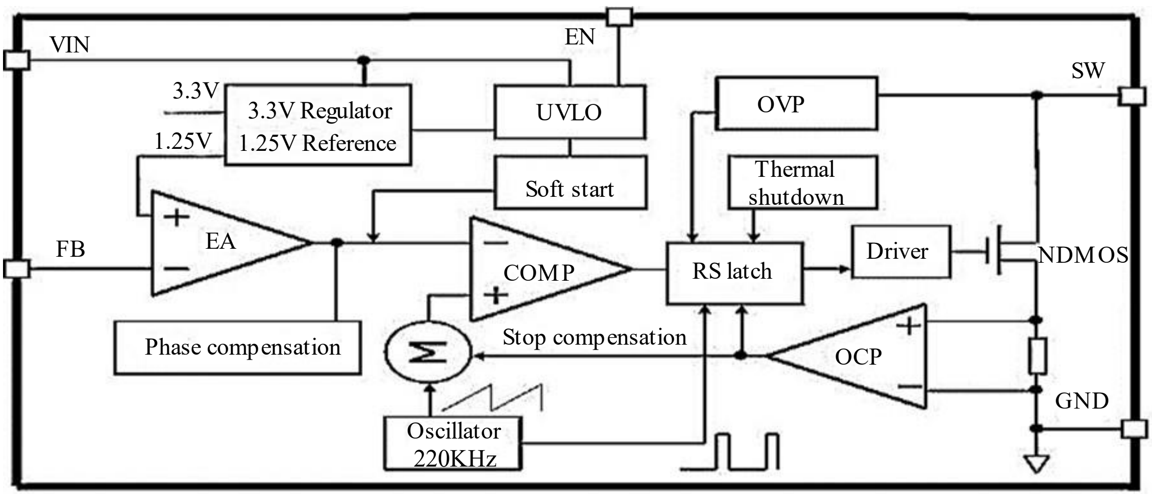

Figure 9. An XL6019's functioning schematic for a DC-DC boost conversion [40].

The function block diagram begins with the input stage. It consists of the input voltage source, which is generally compatible with a wide variety of power sources and may vary from 5V to 32V. This step also includes input protection techniques to safeguard the circuit from voltage spikes or abnormalities that could potentially harm the module. The error amplifier is located in the center of the function block diagram. This part makes a comparison between the reference voltage and the feedback voltage that is obtained from the output. Any difference in these voltages produces an error signal, which instructs the stages that follow to modify the output voltage appropriately. This feedback loop makes sure that the output voltage remains constant and controlled even when the input or load fluctuates [40].

An oscillator and a pulse-width modulation (PWM) comparator work together to regulate the switching transistor's duty cycle. It produces a square-wave signal that controls the duty cycle and switching frequency, dictating how long the transistor is ON or OFF. This procedure controls the output voltage and energy transfer of the XL6019 DC-DC boost converter.

The function block diagram includes the driver circuit, typically a MOSFET or BJT transistor that regulates the power switch. This switch controls whether energy flows from the input to the output by responding to signals from the PWM comparator. The switch changes the input voltage to produce the desired, higher output voltage. The output stage includes the voltage-setting and output filter components. In order to provide the load with a steady and filtered DC voltage, this part smooths out the switching output voltage. Typically, it consists of an output capacitor, an output inductor, and sometimes a network of voltage-setting resistors. Together, these components reduce output ripple and keep the voltage supply constant. In addition to the primary functioning components, the XL6019 also has control and protective systems. These consist of functions like soft start, thermal shutdown, and overcurrent protection. Thermal shutdown defends against damage from extreme heat, while overcurrent protection shields the circuit from high currents. Soft start protects the module and any attached devices by gradually increasing the output voltage and avoiding abrupt surges during power-on. The XL6019's function block diagram effectively controls input voltage and provides a steady, adjustable output voltage of the circuit.

BATTERY MANAGEMENT SYSTEM FOR MINI-UPS

In the field of lithium-ion and lithium-polymer battery technologies, a 2S BMS, or 2-series Battery Management System, is an essential part [41]. The main function of a 2S BMS is to monitor and control the performance and health of two-cell battery configurations. It is essential for keeping the balance between the various cells in the pack and making sure that they are all operating within safe voltage ranges. Maintaining this equilibrium is essential for optimizing the battery pack's overall capacity and longevity. Enabling balanced charging is one of a 2S BMS's primary duties. The BMS monitors and regulates each cell's charging process to prevent overcharging, which could lead to reduced battery life, overheating, or even safety hazards. In addition, the BMS prevents over-discharge, which is another crucial component of battery safety. In order to avoid damage and possible failure, the BMS steps in whenever any cell falls below a safe voltage threshold. To put it simply, a 2S BMS is like a guardian, maximizing the life, safety, and performance of two-cell lithium-polymer or lithium-ion battery packs. A circuit diagram of the lithium-ion battery management system (BMS-2S) is shown in Fig. 10. A printed circuit board (PCB) is used to attach a small lithium battery charger protection module. This small and sophisticated BMS module incorporates functions such as overcharge, over-discharge, over-current protection, and short circuit protection [42]. Flexible printed circuit boards made from thermoplastic polymers like polyethylene terephthalate PET and rigid ones made from thermosetting polymers like epoxy composites are the major varieties. They offer mechanical support, electrical connection, and insulation using insulating materials like fiberglass or plastic. PCB substrates include FR-4 and Polyimide. High-speed, high-frequency applications employ PTFE, a non-resistance plastic. Flexible PTFE is ideal for tight tolerance applications. It's lightweight and versatile, making it useful across industrial sectors.

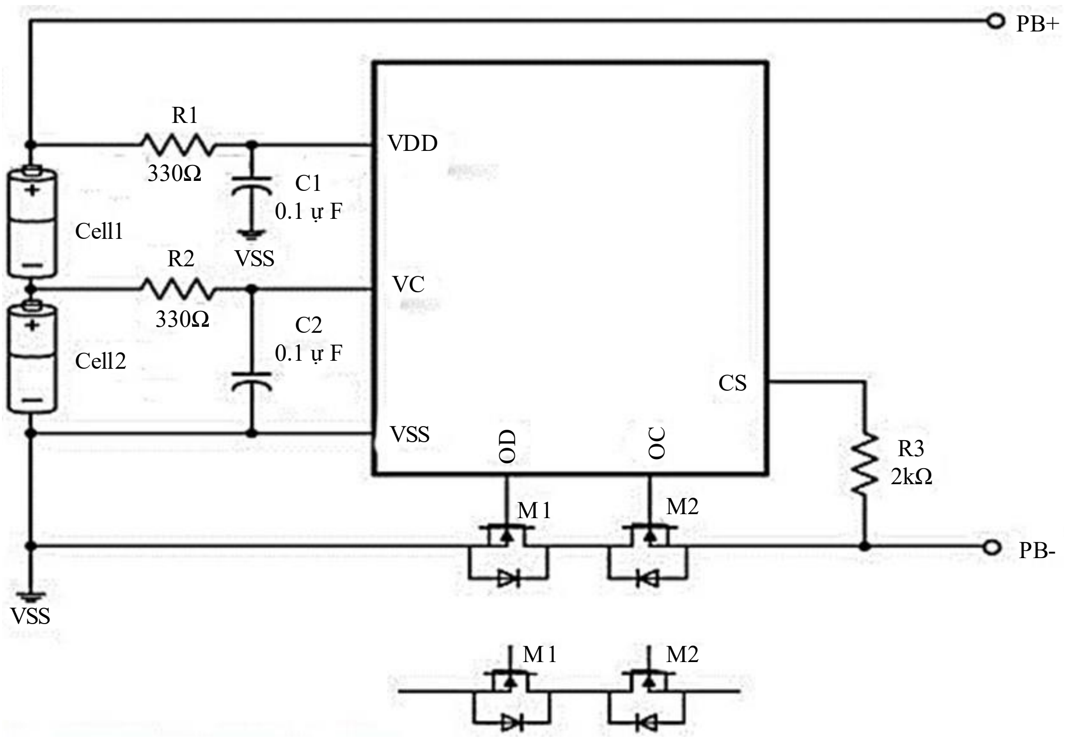

Figure 10. Circuit diagram of the lithium-ion battery management system (BMS-2S) [43].

It is simple to install and compatible with all portable devices. The 2S 5A BMS HX-2S-01 is equipped with an integrated three-stage over-current detection circuit capable of identifying over-current 1, over-current 2, or load short circuits. MOS transistors regulate the process of charging and discharging batteries. MOSFET sensors consist of three layers: a silicon semiconductor, a silicon oxide insulator, and a catalytic metal. These layers enable the generation of an electric current when a voltage is applied. In this scenario, a Battery Management System (BMS) ay include a pre-charge mechanism to ensure the safe connection of the battery to various loads. This system also prevents the occurrence of large inrush currents that might potentially harm capacitors. Fig. 11 shows the Lithium-ion Battery Management System (BMS-2S) operational diagram for various preventive measures, including safeguarding against short circuits. It has three types of protection: overcharge, over-discharge, and overcurrent [43].

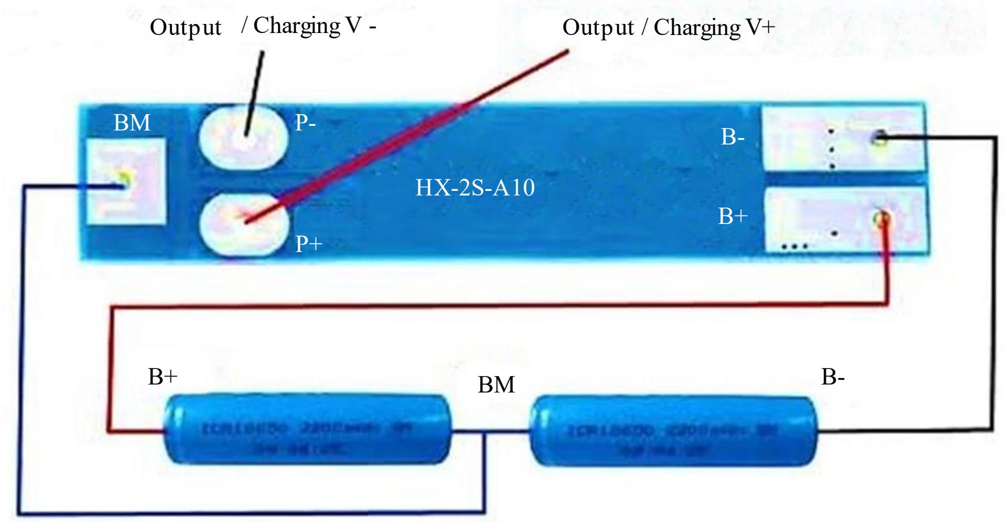

Figure 11. Operational diagram of the lithium-ion battery management system (BMS-2S) [44].

Importance of the Schottky Diode

A metal-semiconductor junction is established by combining a metal with a semiconductor, resulting in the formation of a Schottky barrier instead of a standard diode's semiconductor-semiconductor junction. The semiconductor material often used is N-type silicon, whereas the metals frequently utilized include molybdenum, platinum, chromium, or tungsten [45]. The Schottky diode IN5822 is well-known for its fast performance and effective rectification abilities. Its metal semiconductor junction architecture, which makes it a member of the Schottky barrier diode family, enables quicker switching and less forward voltage drop than typical silicon diodes. With a forward voltage drop of around 0.45 volts at a forward current of 3 amperes, the IN5822 is especially well-suited for applications where low voltage losses are crucial. The Schottky architecture, which reduces switching time and improves efficiency, is perfect for applications where high-frequency operation is crucial. When looking for a diode solution that strikes a balance between performance, speed, and efficiency in a variety of electronic systems, from power supplies to battery charging circuits, designers often turn to the IN5822. The Schottky properties of the IN5822 are highly regarded for their ability to maximise the efficiency of power management systems and electrical equipment.

RESULTS AND VALIDATION OF THE EXPERIMENT

The purpose of the XL4015 is to provide the 8-volt continuous output that is required to charge the batteries from the 2S BMS. Whatever the XL4015's input voltage, if it falls within the input voltage range, the output will be 8 volts (as previously set by the user for a particular application). Since we are utilizing lithium ion batteries, it is necessary to constantly check the charging conditions. To safeguard the circuit, disconnect the batteries if a malfunction arises. 2S BMS safeguards the batteries from over-voltages, over-currents, under-voltages, temperature rises, etc. The batteries are connected in both parallel and series configurations, resulting in a total of two sets. Therefore, a desirable output voltage of 8V and a capacity of 4000 mAh will be attained. In essence, it's a step-up chopper. The task of the XL6019 is to provide a steady 12 volt output, which is required to operate the load from the 2S BMS.

Whatever the XL6019's input voltage, assuming it falls within the input voltage range, the output will be 12 volts (which the user has previously adjusted for a particular purpose). DC loads, such as Wi-Fi routers and CCTV cameras, will be the load in this scenario. The design structure of a reusable battery-powered Mini-UPS for networking applications. The Figure 12 illustrates the structural architecture of a Mini-UPS powered by a rechargeable battery that may be used frequently. By modifying the trim port, you may alter the XL4015's output voltage and current to charge the batteries (8V, 2A). To get an output voltage of 12 volts, adjust the trim port of the XL6019 module. Use a power DC adapter to provide the circuit's input, and then connect the output to a 12V DC application.

Figure 13 presents the experimental validation of a Mini-UPS for networking applications powered by a reusable battery.

Table I and Table II show these experimental results in two different modes of operation. They are as follows:

Table 1. Router Running on Direct Power Supply [47].

Device	Input voltage	Output voltage	Device status
Xl4015	12 Volts	8 Volts	ON
XL6019	-	-	OFF
2S BMS	8 Volts	8 Volts	ON
Battery Pack	8 Volts	-	Charging
Router	12 Volts	-	ON

Table 2. Router running on battery supply [47].

Device	Input voltage	Output voltage	Device status
Xl4015	-	-	OFF
XL6019	8 Volts	12 Volts	ON
2S BMS	8 Volts	8 Volts	ON
Battery Pack	-	8 Volts	Discharging
Router	12 Volts	-	ON

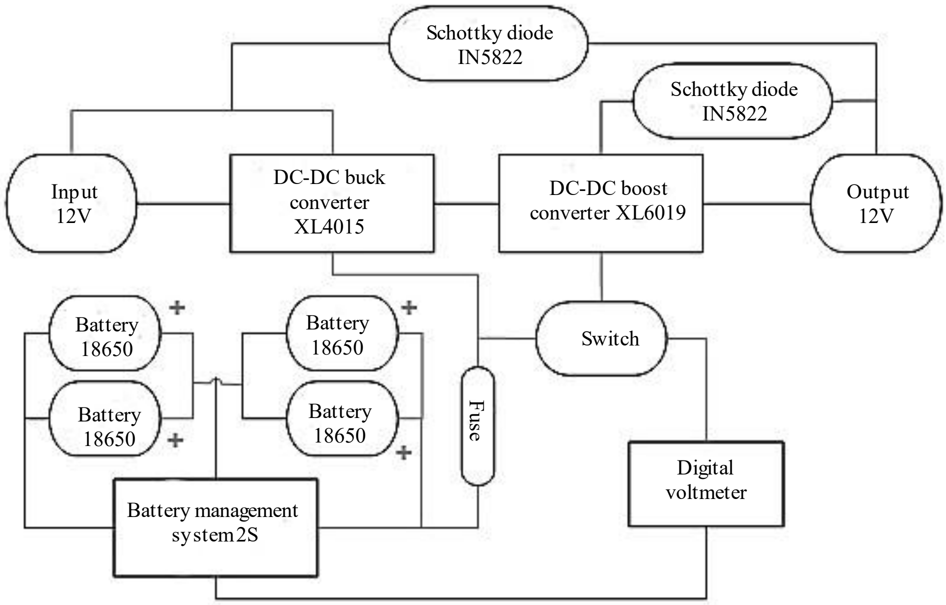

Figure 12. Block diagram of the design structure of a reusable battery-powered Mini-UPS.

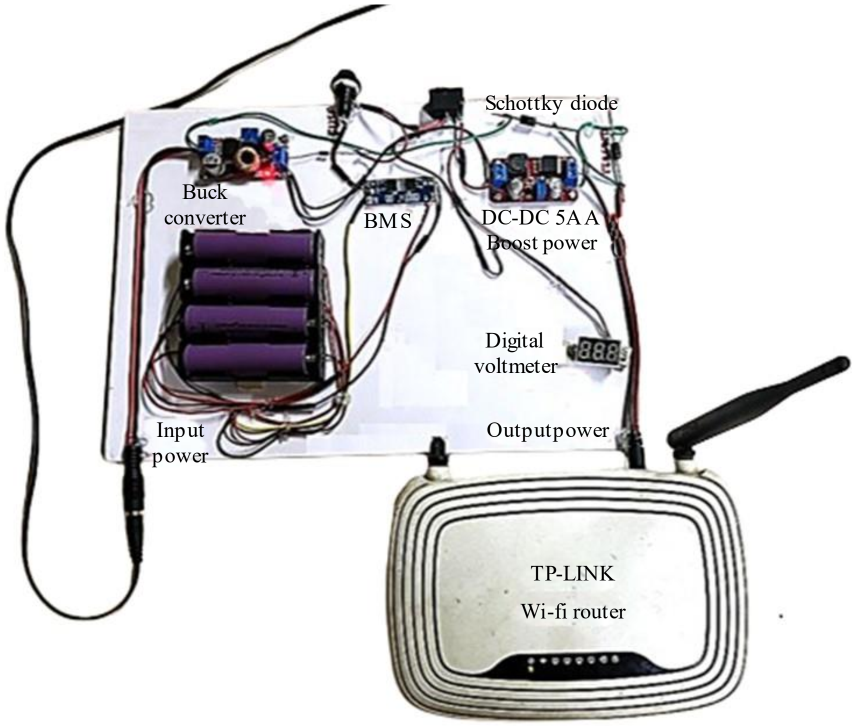

Figure 13. An experimental validation of a Mini-UPS powered by a reusable battery for networking applications.

The required inputs were given, and the output side exhibits the expected outcomes. This circuit enables the router to operate for four hours.

CONCLUSIONS

Currently, there is a high demand for lithium-ion batteries due to their exceptional performance. A Mini-UPS for Wi-Fi Router is a small and easily transportable device that provides auxiliary power to your Wi-Fi router in the event of power failures or disruptions. It guarantees continuous internet access, enabling you to remain connected even in the event of a power outage. The XL4015 variant of the DC-DC Buck converter provided power to devices with moderate to relatively high loads, up to its maximum output current. Its capacity to efficiently regulate higher input voltages to desired lower output voltages has established it as a widely favored choice for many electronics applications. The XL4015 Buck converter module is a best-suited integrated circuit for Buck (step-down) DC-DC conversion in electrical devices, efficiently regulating voltage. The XL6019 is a versatile and efficient step-up (boost) DC-DC converter that offers excellent power regulation for many electronic applications. Additionally, it has remarkable stability in efficiently converting lower voltages to higher ones. The BMS supervised and controlled the charging procedure of each cell to avoid overcharging, which might result in reduced battery lifespan, excessive heat generation, or even pose safety risks. Furthermore, the BMS also served the important function of safeguarding against over-discharge, a critical aspect of ensuring battery safety.

Communication infrastructure often requires small size, lightweight design, low energy use, and the ability to be easily transferred. Flexible polymer substances are useful for making wireless devices. Polymers having low dielectric constants might be advantageous for high-speed wireless communication applications, such as antenna interlayer dielectrics, communication cables, and other accessories. A novel-based design and experimental validation of a battery management system powered by Mini-UPS for networking applications have been successfully verified. The proposed study aims to verify the effectiveness and affordability of a new Mini-UPS (uninterruptible power supply) that is specially developed for networking applications. This innovation is expected to make a significant contribution to the industry. The successful development of this technology would enhance the resilience and reliability of networking settings by allowing continued advancements in uninterrupted power supply technologies. The test results met the criteria of modern networking setups by demonstrating a harmonious combination of efficiency and cost-effectiveness. The study also identified areas for potential improvement, such as increasing battery capacity to extend backup durations or exploring environmentally friendly construction components that do not compromise functionality.

These upcoming enhancements can further enhance the usefulness and sustainability of the UPS. Moreover, this analysis can be extended by using novel optimization and machine learning methods to enhance the study of performance and the features of the battery management system. The finding has significant potential for future applications in networking and security, particularly in the context of enduring social beneficiary applications.

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