International Journal of Electrical, Electronics & Communication Engineering (IJEECE)
DOI: 10.5281/zenodo.13997511

Research Article

Implementation And Analysis of a 5v Rechargeable Power Supply for Microcontroller-Based Application

Gabriel Ebiowei Moses[1] and Priye Kenneth Ainah [2]

[12]Department of Electrical and Electronic Engineering, Niger Delta University, Amassoma, Wilberforce Island, Bayelsa State, Nigeria

Cite as:
Moses, G. E. & Ainah, P. K. (2024). Implementation And Analysis of a 5v Rechargeable Power Supply for Microcontroller-Based Application. *International Journal of Electrical, Electronics & Communication Engineering, 5(2), 12-19.* https://doi.org/10.5281/zenodo.13997511

Abstract

This paper presents a cost-effective, easy-to-implement, and efficient 5V rechargeable power supply solution for microcontroller unit-based (MCU-based) applications. The 5V rechargeable system consist of an XL4015, 5V DC-DC Bulk Converter and a four series (4S) 40A Battery Management System (BMS). The system is designed to provide a regulated 5V output, making it ideal for portable or remote MCU-based applications where continuous power supply is essential. The system provides safety features, including short circuit and overcurrent protection, to prevent damage to the MCU or other connected devices. The system was tested for performance under no load and on-load conditions, demonstrating its ability to deliver stable voltage and maintain charging efficiency. From the results obtained, the system provides a constant 5V when the system is subjected to varying voltages from a variable power source and from a four series (4S) 40A Battery Management System (BMS). The results show that the system worked perfectly well. The system is versatile and can be applied to a wide range of projects, particularly in portable and off-grid scenarios.

Keywords: Microcontroller-Based Application; Rechargeable Power Supply; DC-DC Bulk Converter; Battery Management System (BMS)

Introduction

Power supply systems are fundamental components in modern electronic devices, providing the necessary electrical energy to ensure proper functionality. The increasing demand for efficient, reliable, and portable power solutions, especially for low-power applications like microcontroller-based systems, has driven the need for customized power supply designs (Eliasson, 2008). Microcontroller units (MCUs), widely used in embedded systems, automation, and Internet of Things (IoT) devices, require stable and consistent voltage levels to operate efficiently, typically in the range of 3.3V to 5V (Dutta & Khurana, 2021; Ghosh, et al., 2018). In the realm of embedded systems and microcontroller-based projects, a reliable and efficient power supply is crucial for ensuring the functionality and longevity of electronic devices. The increasing complexity and power demands of modern microcontrollers and associated peripherals have highlighted the need for optimized power solutions that can provide consistent voltage levels while being energy-efficient and user-friendly. A common voltage requirement for many MCU-based projects is 5V, which aligns with the operational standards of various microcontrollers and sensors (Khan et al., 2019). For critical MCU applications, such as those in medical devices, industrial control systems, or communication networks, uninterrupted power is essential. Uninterruptible Power Supplies (UPS) are systems designed to provide backup power in case of a primary power failure, ensuring continuous operation. UPS systems often use batteries or supercapacitors to deliver temporary power until the primary power source is restored or an alternative solution is engaged. Traditional power sources such as disposable batteries or fixed-voltage adapters often fall short in terms of portability, efficiency, and sustainability. This has led to the exploration of rechargeable power solutions that can offer both flexibility and environmental benefits (Smith & Thomas, 2021). The 5V power supply is particularly crucial in microcontroller-based applications due to its compatibility with numerous digital components, sensors, and actuators. This voltage level ensures the stable operation of

MCUs and peripherals, making it a standard in most embedded system designs. However, designing and constructing a rechargeable power supply that not only provides this constant voltage but also offers protection against overcharging, short circuits, and overloads presents technical challenges. The development of a rechargeable 5V power supply for MCU-based applications is a response to the growing need for efficient, portable, and cost-effective power solutions. Such systems must integrate energy storage components (e.g., rechargeable batteries), voltage regulation circuits, and protection mechanisms to ensure long-term reliability. Given the increasing use of MCUs in fields such as robotics, home automation, and sensor networks, a dependable rechargeable power supply is vital to maintain uninterrupted operation. Lithium-ion (Li-ion) batteries have emerged as a preferred choice for rechargeable power sources due to their high energy density, low self-discharge rate, and long cycle life (Yang et al., 2020). However, integrating Li-ion batteries into MCU-based systems requires careful design to ensure proper voltage regulation and battery management. The challenge lies in designing a power supply system that not only delivers a stable 5V output but also incorporates efficient charging mechanisms and protection features (Chen et al., 2018). This paper presents a comprehensive approach to designing and constructing a rechargeable 5V power supply specifically for MCU-based projects. The proposed solution combines a Li-ion battery with a step-up converter and a charging management system to achieve a stable and reliable power output. The step-up converter addresses the challenge of maintaining a consistent voltage as the battery discharges, while the charging management system ensures safe and efficient battery charging (Lee et al., 2022). This paper presents the implementation and performance analysis of a portable 5V rechargeable power source for MCU-based applications, utilizing an XL4015 buck converter and a 4S 40A Battery Management System (BMS) board.

Rechargeable Power Supply

Rechargeable power supplies are gaining popularity, especially for portable electronics and embedded systems (Hodges, 2013; Yüksel, 2019). These systems use rechargeable batteries (such as lithium-ion, nickel-metal hydride, or lead-acid batteries) as their power source, allowing them to be used repeatedly without the need for constant replacement. Rechargeable power supplies are essential in applications like smartphones, laptops, electric vehicles, and microcontroller-based systems, where continuous or portable power is needed.

The advantages of rechargeable power supplies include:

i. Cost-Effectiveness: Although rechargeable power supplies have a higher initial cost, they reduce long-term costs by eliminating the need for frequent battery replacements.
ii. Environmental Sustainability: Rechargeable batteries help reduce environmental waste, making them more eco-friendly compared to disposable batteries.
iii. Convenience: Rechargeable systems offer the convenience of recharging the battery instead of replacing it, providing longer operational times and ensuring uninterrupted power in critical systems.

In microcontroller-based systems, a stable and reliable power supply is critical to the overall performance and functionality of the system. Microcontrollers typically require a precise voltage range (e.g., 3.3V or 5V) to operate correctly. If the power supply voltage is too low, the microcontroller may fail to function or cause errors in the system. If it is too high, it can damage the microcontroller and other sensitive components. Power supplies are fundamental to any electronic system, ensuring that devices receive the necessary energy in the correct form and voltage. From simple battery systems to complex AC-to-DC converters, power supplies are tailored to meet the specific needs of each application. In modern systems, especially in microcontroller-based applications, rechargeable power supplies provide the dual advantage of portability and sustainability, making them an essential component in today's electronics landscape.

Material and Methods

Materials Used

The major components that were used in the design, construction and testing of the rechargeable 5V power supply for MCU-based projects are:

1. XL4015, 5V Bulk Converter
2. 4S 40A BMS (Battery Management System) Board
3. Variable DC power supply
4. Battery pack (4 cells in series)

5. Wires and connectors
6. Soldering tools
7. Digital Multimeter (for checking connections)
8. Oscilloscope (for monitoring both input and output signals)

X14015, 5V Bulk Converter

X14015, 5V Bulk Converter is a DC-DC converter module designed to efficiently convert input voltages to a stable 5V output. X14015, 5V Bulk Converter is a DC-DC converter module is used in this paper because it has high efficiency and reliability, Wide input voltage range and stable output, Compact size and low heat generation, Affordable and widely available and Suitable for a variety of applications, from hobby projects to industrial designs. Figure 1 shows the schematic of the XL4015 Board.

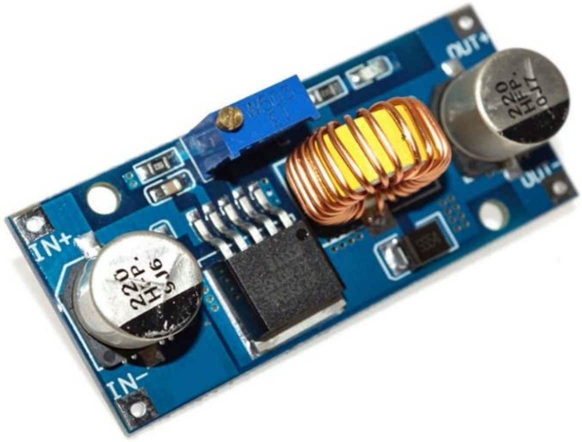

Fig 1: XL4015, 5V bulk converter

Energy Storage Solutions for MCUs

Energy storage solutions are critical components in microcontroller-based systems (MCUs), especially for applications that require uninterrupted power or operate in environments with inconsistent or no access to external power sources. Effective energy storage ensures that MCUs can maintain stable performance, extend operational life, and manage power usage efficiently. Uninterrupted power is essential for critical MCU applications, such as those in medical devices, industrial control systems, or communication networks. Uninterruptible Power Supplies (UPS) are systems designed to provide backup power in case of a primary power failure, ensuring continuous operation. UPS systems often use batteries or supercapacitors to deliver temporary power until the primary power source is restored or an alternative solution is engaged. As MCU applications expand into fields like IoT, wearables, and renewable energy systems, innovative energy storage solutions will play an increasingly important role in extending device life, improving sustainability, and enabling autonomous operation (Ahmad & Zhang, 2021). There are various energy storage solutions available, each with unique characteristics that make them suitable for different MCU-based applications such as Lithium-Ion (Li-ion) Batteries, Nickel-Metal Hydride (NiMH) etc. (Selva, 2024) Batteries are the most common energy storage solution for MCUs, providing portable and reliable power for a wide range of devices. They store electrical energy in chemical form and convert it back into electrical energy when needed. Different types of batteries are used based on specific energy demands, size, lifespan, and recharging capabilities. From traditional batteries to cutting-edge energy harvesting solutions, the choice of energy storage is influenced by factors like power requirements, recharging capabilities, and environmental conditions. The power consumption and operational time of the MCU dictate the energy capacity needed from the storage solution. For portable or wearable applications, lightweight and compact energy storage options, Li-ion batteries or supercapacitors, are preferred (Wang, et al., 2014; Rani, et al., 2021). Rechargeability: Systems that require frequent recharging benefit from rechargeable batteries, energy harvesting solutions, or hybrid systems that combine batteries with supercapacitors. Certain applications may require energy storage solutions that can operate in harsh or variable environments, such as high temperatures, humidity, or vibration. Figure 2 shows the 4S, 40A Li-ion Lithium Battery Connection Detail.

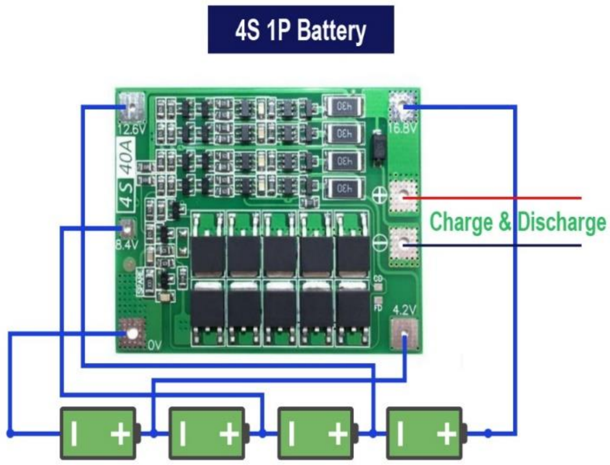

Fig 3.2: 4S, 40A Li-ion Lithium Battery Connection Detail

In the context of our rechargeable 5V power supply for MCU-based projects, the 4S, 40A BMS Board can be used to Protect and manage the battery pack powering any MCU-based board, fingerprint scanner, and other components, and ensure safe and reliable power supply during extended use or backup power situations. It also prevents damage to the battery pack and connected devices from excessive voltage, current, or temperature fluctuations. The output voltage of the 4S, 40A BMS Board is dependent on the state of charge of the 4-series lithium-ion battery pack it's managing.

Method of Implementation

Since it's a 4S (4-series) BMS, the output voltage will be the sum of the voltages of the three cells in series will be 14.8V and the charged voltage will be 16.8V and the discharge cut-off voltage is 12.0 V. So, the output voltage of the 4S, 40A BMS Board will range from approximately 12.0V to 16.8V, depending on the battery's state of charge. This output voltage of the 4S, 40A BMS board is in synergy with the input requirements of the XL4015 board as shown in Figures 3 and 4. Keep in mind that the BMS Board is designed to protect the battery and prevent overcharge/discharge, so it will regulate the output voltage to stay within safe limits. To sync the XL4015 5V Bulk Converter and the 4S, 40A BMS Board, you'll need to connect them in a way that allows the BMS to regulate the battery voltage and the XL4015 to convert the output to a stable 5V. Connecting a 4L4015 board (DC-DC Bulk Converter board) to a 4S, 40A BMS (Battery Management System) board involves several steps. It's crucial to make sure one connects everything correctly to ensure safe operation and functionality of your battery pack. Here's a general guide on how to do it:

Steps by step Connection of the Boards:

Step 1: Connect the Battery Pack to the BMS:

1. Positive Terminal: Connect the positive terminal of the battery pack to the BMS's positive input terminal.
2. Negative Terminal: Connect the negative terminal of the battery pack to the BMS's negative input terminal.
3. Balance Wires: Connect the balance wires from the BMS to the battery cells. The BMS should have a series of balance wires (typically 5 or 6 wires for a 4S system) that correspond to the cells. These wires are usually labelled (e.g., B-, B1, B2, B3, B4, and B+).

Step 2: Connect the 4L4015 Board to the BMS:

1. Power Supply: Ensure the 4L4015 board is powered appropriately. This might involve connecting it to a power source directly from the battery pack or from the BMS's output terminals if it has a power supply output for monitoring systems.

2. Signal Wires: Connect the signal wires from the 4L4015 board to the BMS. These are typically used for communication and data transfer between the BMS and the monitoring board. Check the documentation for the 4L4015 board for exact wiring instructions. This usually involves:
    a. Connecting the monitoring board's inputs to the corresponding monitoring or data pins on the BMS.
    b. If the 4L4015 board has communication lines (like UART, I2C, etc.), ensure these are correctly connected to the BMS's communication interface.

Step 3: Double-Check Connections:

1. Verify Correct Wiring: Make sure all connections are secure and correctly matched. Double-check the balance wires and ensure they are connected to the correct cells.
2. Inspect for Short Circuits: Before powering up, inspect all connections for potential short circuits or incorrect wiring.

Step 4: Test the System:

1. Power On: Once everything is connected, power on the system. The 4L4015 board should start displaying or monitoring data from the BMS.
2. Check Functionality: Verify that the BMS is properly managing the battery pack and that the 4L4015 board is correctly receiving and displaying the data.

The 4L4015 board was successfully connected to the 4S 40A BMS board following the above steps. If you encounter any specific issues or have questions about particular connections, referring to the detailed manuals for each board is always a good idea. Note that the CHARGE and DISCHARGE pins of the 4S 40A BMS board are directly connected to the XL4015, 5V bulk converter as shown in Figure 4, taking cognizance of the polarities, while the output port is connected to LOAD.
By syncing these two components, I was able to develop and build a stable, reliable and efficient power supply for any model MCU based system that uses 5V.

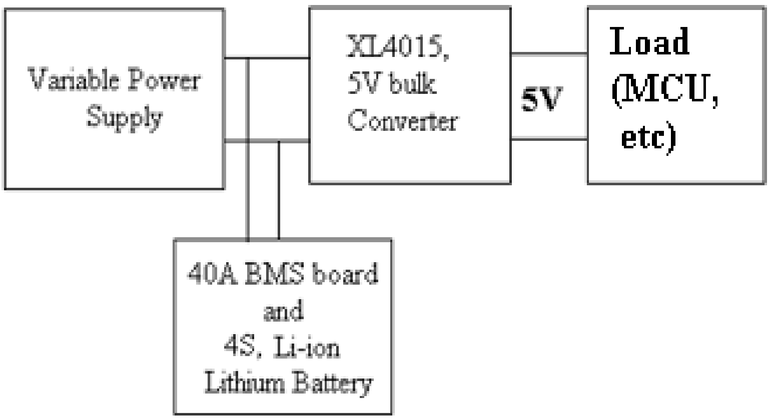

Fig 3: Rechargeable 5V power supply configuration.

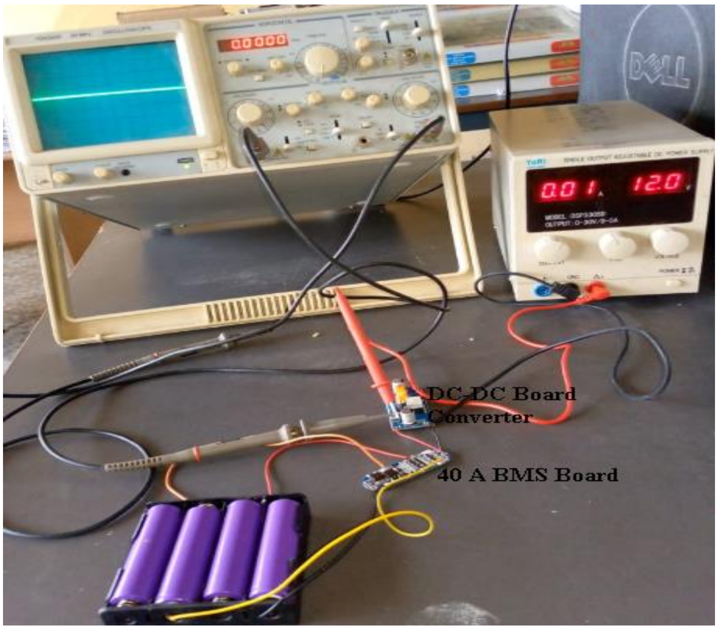

Fig 4: Implemented 5V Rechargeable Power Supply

Results and Discussion

The results in Tables 1 and 2 were obtained from rigorous system tests with varying input voltages on the XL4015 DC-DC bulk converter under no load and on-loaded conditions. Table 1 shows a constant 5V from the output of the bulk converter when different voltages from the variable DC voltage source ranging from 7V to 23 V were applied to the input of the XL4015 DC-DC bulk converter under no load condition. The voltage range is within the manufacturers' specified range for characteristic tests. Also, Table 2 shows a constant 5V from the XL4015 DC-DC bulk converter output when the 4S, 40A Li-ion Lithium Battery was applied to the system under on-load conditions. The result indicates that the lithium batteries were fully charged initially and allowed to discharge gradually over the test period. The output of the BMS is recorded at graduated values, as depicted in Table 2.

Table 1: Output of Bulk Converter without Load

S/N	*Output of Variable PS*	*XL4015, 5V Bulk Converter Output*
1	7	5
2	9	5
3	11	5
4	13	5
5	15	5
6	17	5
7	19	5
8	21	5
9	23	5

Table 2: Output of Bulk Converter under Load

S/N	*4S 40A BMS Board Output*	*XL4015, 5V Bulk Converter with Load*
1	16.25	*5*
2	15.75	*5*
3	15.25	*5*
4	14.75	*5*
5	125	*5*
6	13.75	*5*
7	13.75	*5*
8	12.75	*5*
9	12.75	*5*

Conclusion

The implementation of the 5V rechargeable power supply for MCU-based applications aimed to provide a reliable, efficient, and rechargeable power source for a variety of microcontroller projects. This project successfully met its objective by integrating a regulated 5V output, rechargeable battery system, and safety features that ensure consistent performance, even in fluctuating power conditions. Testing and evaluation showed that the 5V rechargeable power supply system performed well under varying loads and maintained a stable 5V output to the microcontroller. Challenges encountered during the implementation phase, such as component selection and circuit optimization, were effectively addressed through thorough testing and adjustments. The final product not only met the necessary performance criteria but also incorporated features like short-circuit protection and overcurrent safety to ensure long-term reliability. The paper demonstrated the feasibility of building a rechargeable 5V power supply that can be used in various microcontroller-based applications. It is a valuable addition to the toolkit of engineers and hobbyists who require portable, rechargeable power solutions for their projects. Moving forward, further improvements could focus on enhancing battery capacity, reducing charging time, and incorporating additional features like USB output options, making the system more versatile and user-friendly for a wider range of applications.

References

Ahmad, T., & Zhang, D. (2021). Using the internet of things in smart energy systems and networks. *Sustainable Cities and Society*, 68, 102783.

Chen, Y., Wang, J., & Li, M. (2018). Design and implementation of a battery management system for lithium-ion batteries. *IEEE Transactions on Power Electronics*, 33(4), 2981-2992.

Dutta, U., & Khurana, N. (2021). The Internet of Things Using NODEMCU. Blue Rose Publishers.

Eliasson, J. (2008). Low-power design methodologies for embedded internet systems (Doctoral dissertation, Luleå tekniska universitet).

Ghosh, K. U. N. D. A. N., Bhowmick, M., & Joddar, D. (2018). Globally controlled multiple relays using NODE MCU.

Hodges, S. (2013). Batteries not included: powering the ubiquitous computing dream. *IEEE Computer.*

Khan, M. A., Hussain, M. S., & Khan, N. U. (2019). A comprehensive review of microcontroller power supply design for embedded systems. *Journal of Electrical Engineering & Technology*, 14(2), 593-605.

Lee, J., Park, K., & Kim, H. (2022). Advanced charging management techniques for lithium-ion batteries in portable devices. *Energy Reports*, 8, 1350-1362.

Rani, S., Kumar, N., & Sharma, Y. (2021). Recent progress and future perspectives for the development of micro-supercapacitors for portable/wearable electronics applications. *Journal of Physics: Energy*, 3(3), 032017.

Selva, J. (2024). Trends and Preferences: A Study on Electric Two Wheeler Adoption in The Deltaic Regions of Tamilnadu. Laxmi Book Publication.

Smith, R., & Thomas, D. (2021). The role of rechargeable batteries in modern electronic devices. *Journal of Sustainable Electronics*, 10(3), 145-158.

Wang, X., Lu, X., Liu, B., Chen, D., Tong, Y., & Shen, G. (2014). Flexible energy-storage devices: design consideration and recent progress. *Advanced Materials*, 26(28), 4763-4782.

Yang, Y., Xu, Z., & Zhang, T. (2020). Lithium-ion battery technology and applications: A review. *Energy Storage Materials*, 27, 1-23.

Yüksel, M. E. (2019). The design and implementation of a batteryless wireless embedded system for IoT applications. *Electrica*, 19(1), 1-11