DESIGN AND DEVELOPMENT OF A MULTI-OUTPUT DC-DC BUCK CONVERTER FOR OFF-GRID SOLAR-POWERED DC HOMES

A Project report is submitted in partial fulfillment of the requirements for the award of Degree of Bachelor of Science in Electrical and Electronic Engineering.

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JANUARY, 2025

DECLARATION

I hereby declare that this project **"Design and Development of a Multi-Output DC-DC Buck Converter for Off-Grid Solar-Powered DC Homes"** represents my own work which has been done in the laboratories of the Department of Electrical and Electronic Engineering under the Faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering, and has not been previously included in a thesis or dissertation submitted to this or any other institution for a degree, diploma or other qualifications. I have attempted to identify all the risks related to this research that may arise in conducting this research, obtained the relevant ethical and/or safety approval (where applicable), and acknowledged my obligations and the rights of the participants.

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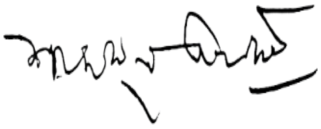
APPROVAL

The project entitled **“Design and Development of a Multi-Output DC-DC Buck Converter for Off-Grid Solar-Powered DC Homes”** submitted by **Mahmudul Hasan Remon (203-33-1314), Md. Abu Raihan (203-33-1325), Ashraful Abedin (203-33-1348) and Md. Murad Parvej (203-33-1342)** has been done under my supervision and accepted as satisfactory in partial fulfillment of the requirements for the degree of **Bachelor of Science in Electrical and Electronic Engineering** in **January, 2025.**

Signed



Professor Dr. M. Shamsul Alam
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Dedicated

To

Our Beloved Parents

Whose constant support and encouragement have shaped us into who we are today.

&

Also our respected late Department Head,

Professor Dr. Md. Shahid Ullah

Whose wisdom and life lessons will always inspire us in the days to come.

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LIST OF ABBREVIATIONS

BAETE	Board of Accreditation for Engineering and Technical Education
DIU	Daffodil International University
DC	Direct Current
AC	Alternating Current
PWM	Pulse Width Modulation
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
PCB	Printed Circuit Board
EMI	Electromagnetic Interference
IEC	International Electro-technical Commission
ISO	International Organization for Standardization
CISPR	International Special Committee on Radio Interference
IC	Integrated Circuit

LIST OF SYMBOLS

Symbol	*Name of the symbol*
Δ	Delta
O	Knot
µ	Micro
Ω	Ohm
°C	Degree Celsius

ACKNOWLEDGEMENT

First of all, we want to give thanks to **Almighty Allah**. With his blessing we are able to complete our work with best effort.

We want to pay our utmost respect to our Supervisor **Professor Dr. M. Shamsul Alam, Dean & Professor** of the **Department of EEE, Daffodil International University** for who has given us the chance to work on an impactful idea and taken care of every issue of development of this concept. Then we would like to take this opportunity to express gratitude to our supervisor for being dedicated in supporting, motivating and guiding us throughout this project. This project can't be done without his useful advice and help. Also thank him very much for giving us the opportunity to work with this project.

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ABSTRACT

The adoption of renewable energy technologies has seen unprecedented growth in recent years, driven by the urgent need to transition away from fossil fuels and mitigate climate change. Among the various renewable energy solutions, solar power has emerged as a leading contender due to its widespread availability and versatility. In particular, off-grid solar systems are playing a transformative role in providing electricity to remote and underserved areas. These systems, especially those operating on Direct Current (DC), offer significant advantages in terms of efficiency and simplicity by eliminating the need for inverters. However, as DC-powered homes become more prevalent, they face a critical challenge: the varying voltage requirements of modern appliances. Unlike Alternating Current (AC) systems, where appliances are standardized to operate on a fixed voltage, DC appliances often require different voltage levels, such as 12 V for lighting and fans, or higher for refrigerators and specialized equipment. This diversity necessitates the use of multiple DC-DC converters, each tailored to a specific appliance, leading to increased costs, system complexity, and maintenance burdens. Our project aims to address these issues by developing a novel DC-DC converter that can accept a wide input voltage range (24–48 V DC) and provide two distinct outputs: a fixed 12 V DC for standard appliances and a variable DC output to accommodate diverse voltage requirements. The proposed solution is designed to simplify voltage management in DC homes, reduce costs, and enhance overall system efficiency, paving the way for more practical and widespread adoption of DC-powered residential systems.

Keywords: Renewable energy, Solar power, Off-grid systems, Direct Current (DC), DC-DC converters, System efficiency.

CHAPTER 1
INTRODUCTION

1.1 Background

The rise of DC-powered homes represents a significant shift in the renewable energy landscape, particularly in off-grid and remote areas where traditional grid infrastructure is unavailable. Unlike AC systems, which dominate urban grids, DC systems are well-suited for off-grid applications due to their ability to utilize solar energy directly without the need for energy-intensive conversions. This direct use of solar-generated electricity enhances overall system efficiency, reduces energy losses, and minimizes the cost of operation. However, the diverse voltage requirements of household appliances present a unique challenge for DC-powered homes. For example, appliances such as LED lights, which are commonly used in off-grid systems, typically operate on 12 V DC, while other devices like refrigerators, air conditioning units, or certain pumps may require higher voltages ranging from 24 V to 48 V DC. This variability forces homeowners to rely on multiple DC-DC converters, each designed to step up or step-down voltage for specific devices. This multi-converter approach not only increases the initial investment required but also adds complexity to the system, making it harder to install, manage, and maintain. Despite these challenges, DC systems continue to gain popularity due to their inherent efficiency and suitability for renewable energy sources. Recent advancements in DC-DC converter technology have shown promise in addressing some of these challenges by offering more efficient and compact designs. However, the lack of integrated solutions capable of providing multiple voltage outputs from a single input remains a significant bottleneck. This research seeks to bridge this gap by designing a unified DC-DC converter solution tailored for DC-powered homes, leveraging advanced circuit design techniques to meet the diverse voltage needs of modern appliances while maintaining high efficiency and reliability.

1.2 Problem Statement

DC-powered homes are becoming increasingly popular as a sustainable and efficient alternative to traditional AC systems, particularly in off-grid areas. However, these systems face a critical challenge: the varying voltage requirements of appliances necessitate the use of multiple DC-DC converters to step up or step-down voltages to meet specific device needs. For instance, LED lights may require a steady 12 V, while refrigerators, pumps, or specialized equipment might demand higher or adjustable voltage levels. This reliance on multiple converters leads to several problems, including higher costs for purchasing individual converters, increased system complexity, and maintenance challenges. Each converter also contributes to energy losses, reducing the overall efficiency of the system. Homeowners are often burdened with the task of sourcing and managing these converters, which can deter the broader adoption of DC-powered homes despite their inherent advantages. Existing DC-DC converter solutions often cater to specific voltage ranges and lack the versatility to handle the diverse needs of an entire household. This limitation not only hinders the practicality of DC systems but also increases the operational and maintenance burdens on users. Furthermore, the lack of a single, integrated solution complicates the installation process and increases the likelihood of system failures due to mismatched or poorly performing converters. This research aims to address these issues by developing a versatile, multi-output DC-DC converter that can simplify voltage management in DC-powered homes. The proposed solution will provide a fixed 12 V DC output for standard appliances and a variable DC output to meet the diverse voltage requirements of other devices, thereby reducing system complexity, improving efficiency, and lowering costs.

1.3 Aims & Objectives

The overarching goal of this research is to develop an integrated DC-DC converter capable of meeting the diverse voltage requirements of appliances in DC-powered homes, thereby simplifying system design, reducing costs, and improving efficiency. The specific objectives of the study are:

- To design and develop a multi-output DC-DC converter: The proposed converter will accept a wide input voltage range of 24–48 V DC and provide two outputs: a fixed 12 V DC for standard appliances and a variable DC output adjustable to meet the specific voltage needs of diverse devices.

- To enhance system efficiency and performance: The converter will be designed using advanced components and ICs to minimize energy losses, ensuring high efficiency and reliability under varying load conditions.
- To reduce system complexity and costs: By consolidating multiple DC-DC converters into a single device, the proposed solution aims to lower the cost of implementing DC systems while simplifying installation and maintenance.
- To validate the design through simulation and prototyping: The circuit design will be simulated using EasyEDA, and a prototype will be developed to test its real-world performance under controlled laboratory conditions.
- To provide a practical solution for DC-powered homes: The converter will be designed to meet the practical needs of homeowners, ensuring compatibility with a wide range of appliances and facilitating the broader adoption of DC systems in renewable energy applications.

1.4 Methodology

The research employs a structured approach to design, develop, and test the proposed multi-output DC-DC converter. The study begins with defining the input and output voltage requirements based on the needs of common household appliances in DC-powered homes. The converter is designed to accept an input voltage range of 24–48 V DC and provide two outputs: a fixed 12 V DC output and a variable DC output adjustable to different voltage levels. The circuit design process involves selecting advanced ICs, resistors, capacitors, and other components to ensure high efficiency, voltage stability, and thermal performance.

The design is implemented using EasyEDA, a circuit simulation tool, to create the PCB layout and test the circuit's performance in a virtual environment. After the design is finalized, a prototype will be developed at our capstone project LAB then it will be tested in the renewable energy lab under controlled conditions. The prototype is subjected to various load scenarios to evaluate its performance, including energy efficiency, voltage stability, and load regulation.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The role of DC-DC converters in renewable energy systems has been widely studied, with numerous advancements in topology and efficiency reported in recent years [1][2]. Traditional converters, such as buck, boost, and buck-boost configurations, have been optimized for various applications, including solar energy systems, electric vehicles, and industrial processes [3][4]. However, most commercial solutions are designed to address specific voltage requirements, limiting their versatility in applications like DC-powered homes, where appliances often demand varying voltage levels [5][6]. Multi-output converters have been proposed as a solution to this limitation, with studies highlighting their potential to simplify system design and reduce costs [7][8].

2.2 Related Research

The integration of advanced ICs into DC-DC converter designs has enabled the development of compact, efficient solutions capable of meeting stringent performance requirements [9][10]. For instance, research by Kumar et al. (2019) demonstrated the use of synchronous rectification in boost converters to achieve efficiency levels exceeding 95% [11]. Similarly, Liu et al. (2020) explored the use of wide-bandgap semiconductors to improve thermal performance and reliability in high-power converters [12][13]. Despite these advancements, the application of multi-output converters in residential settings remains underexplored, particularly in the context of DC-powered homes [14][15].

Simulation tools like EasyEDA have revolutionized the design and testing process for power electronics, allowing researchers to model complex circuits with precision and identify potential issues before prototyping [16][17]. Studies by Ahmed et al. (2022) and Chen et al. (2021) highlighted the effectiveness of these tools in optimizing PCB layouts and improving overall system performance [18][19][20]. Building on this foundation, this research seeks to address the gap in unified DC-DC converter solutions by developing a versatile device tailored for DC-powered homes [21][22].

2.3 Summary

This highlights the critical role of DC-DC converters in renewable energy systems, particularly in addressing the diverse voltage requirements of modern appliances in DC-powered homes. Existing studies underscore the efficiency advantages of DC systems, which bypass the energy losses inherent in AC conversions, making them particularly suited for off-grid and renewable applications. Traditional converters, such as buck, boost, and buck-boost configurations, have been extensively analyzed for their adaptability and efficiency [1][2][3]. However, these designs often cater to specific voltage ranges, limiting their flexibility in applications requiring multiple outputs [4][5].

Multi-output DC-DC converters emerge as a promising solution, offering the ability to simultaneously provide fixed and variable voltage outputs from a single input source. Research emphasizes their potential to simplify system design, reduce costs, and enhance reliability in DC-powered systems [6][7]. Advanced converter designs, utilizing wide-bandgap semiconductors and synchronous rectification techniques, have achieved efficiency levels exceeding 95%, demonstrating the feasibility of high-performance solutions [8][9][10]. These advancements, coupled with robust thermal management strategies, address the operational challenges posed by varying load demands in residential settings [11][12].

CHAPTER 3
SYSTEM DESIGN

3.1 Introduction

System design is a critical phase in the development of engineering solutions, particularly in renewable energy systems, where efficiency, reliability, and adaptability are paramount. For this research, the system design focuses on developing a versatile DC-DC converter with multi-output capabilities, catering to the voltage requirements of various appliances in DC-powered homes. The design integrates principles of power electronics and circuit optimization to address practical challenges in renewable energy applications, such as energy losses, voltage mismatches, and system complexity.

In DC-powered homes, appliances operate on diverse voltage levels, necessitating a flexible solution that consolidates multiple conversion processes into a single, compact device. The proposed system design incorporates advanced converter topologies, allowing it to accept a wide input voltage range (24-48 VDC) while providing both fixed (12 VDC) and variable DC outputs. This capability ensures compatibility with a broad spectrum of appliances, enhancing the practicality and cost-effectiveness of DC systems.

This chapter outlines the systematic approach to designing the multi-output DC-DC converter, encompassing theoretical analysis, circuit design, component selection, and simulation. Tools such as EasyEDA are utilized to create a precise PCB layout, ensuring optimal performance and manufacturability. Emphasis is placed on achieving high conversion efficiency, robust thermal management, and load adaptability, critical for real-world applications. Additionally, the chapter discusses the integration of protective features, including overvoltage and overcurrent safeguards, to ensure operational reliability.

By detailing the methodologies and principles underpinning the design process, this chapter provides a comprehensive understanding of the technical and practical considerations involved. It serves as a foundation for implementing the proposed system in a laboratory setup and evaluating its performance, ultimately contributing to the advancement of DC-powered home technologies.

3.2 Methods and Materials

When we are transmitting electricity, we must try to keep the voltage higher to reduce the current flow without changing the power transmission. A typical solar system used at houses in our country used DC voltage ranging from 24-48 VDC and most of the DC appliances run between 12 and 24 VDC. So, we need to reduce the voltage at the user end. In this project we will develop a DC-to-DC voltage converter that reduces the voltage. This type of converter is known as buck converter.

The method we are using here is a MOSFET based buck conversion. By using a switching mechanism to step down a higher DC voltage to a lower DC voltage. The operation is based on the principles of energy storage and transfer in inductive and capacitive components, controlled by the MOSFET and a feedback mechanism to regulate the output voltage.

The key & basic component of our buck converter is a switch, a diode, capacitor and a control circuit to regulate the switch.

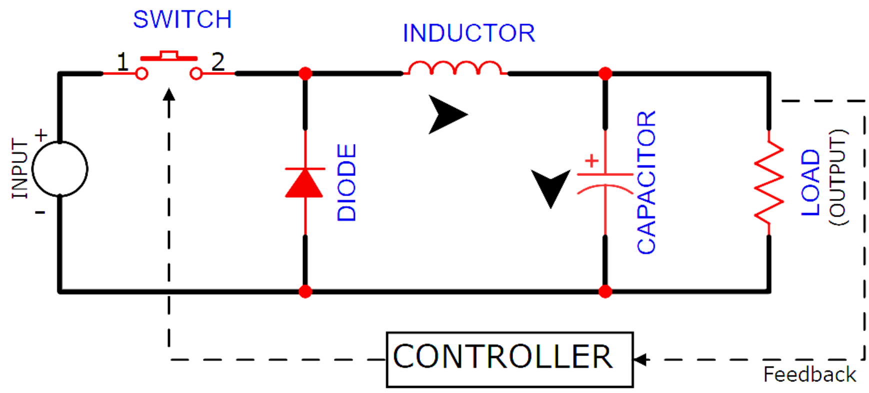

Figure 3.1 Basic configuration of our design

Switch controls the flow of input power into output by turning ON and OFF periodically. The amount of time the switch is on is "Duty cycle". The average output voltage of our Buck converter is controlled using PWM (Pulse Width Modulation) in CCM (Continuous Conduction Mode). Our buck converter working principle is based on storing energy in an inductor. The voltage drop between the inductor is proportional to the difference in the electric current flowing. A switching transistor in between input and output for switching on and off at high frequency. To maintain a continuous output. PWM controls the switching frequency which is our duty cycle. Our output varies depending on the duty cycle.

3.2.1 Working Operation of Our circuit

In our device we will have both fixed voltage output and also variables. Where a potentiometer will be used to vary the duty cycle to change the output voltage. The working operation of our circuit can be explained in two modes. When the switch is ON and when it is OFF. In ON state, the diode becomes reverse biased to the input. Hence, all the input current flows through the inductor. So the DC input current (IDC) flowing in the circuit is equal to the inductor current (IL). We can say IL=IDC.

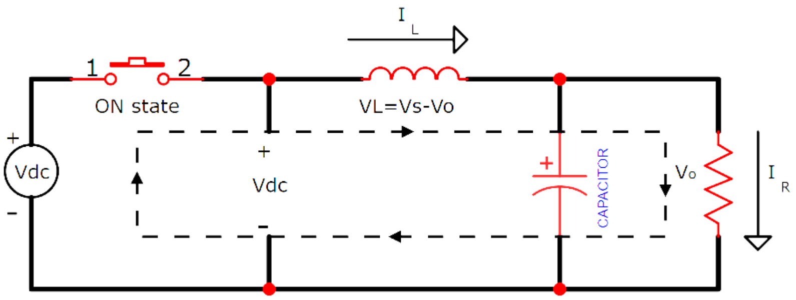

Figure 3.2: Our design circuit in ON State

The inductor charges during ON time. This current further divides into load current (I_O) and capacitor current (I_C). So we can say, $I_L=I_C+I_R$. During this time inductor voltage (V_L) is the voltage difference between source voltage (V_{dc}) and output voltage (V_O). We can say, $V_L=V_{dc}-V_O$. The ON period is determined by the product of duty cycle and total time.

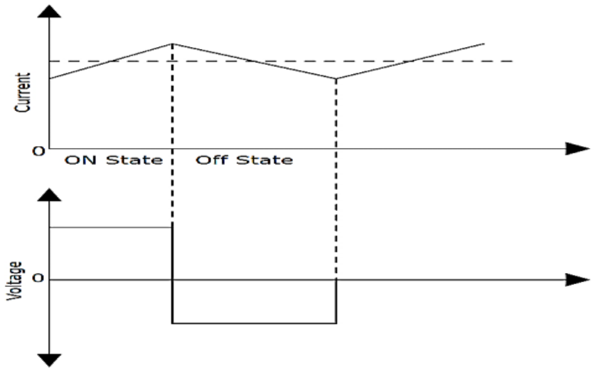

Figure 3.3: Current & Voltage waveform of the inductor

Here we can see the current & voltage waveform of the inductor in ON and OFF state. When the switch is at OFF state the polarity of the inductor reverses and it starts acting like a source. The current at this time flows from the stored energy in the inductor. Our source is disconnected at this time. Therefore, the current flows till the inductor are discharged. The voltage across the inductor is equal to the negative of the output voltage (V_L= -V_O).

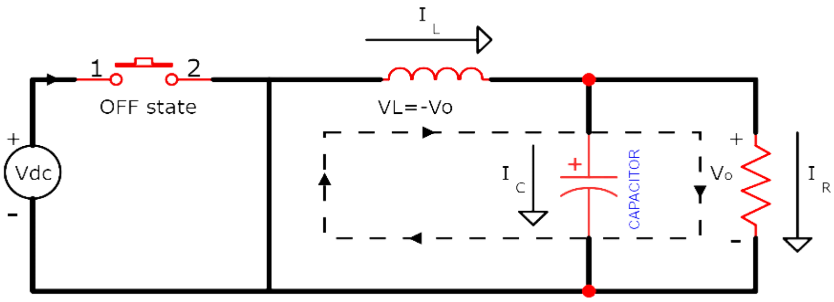

Figure 3.4: Our design circuit in OFF State

At the OFF state, the polarity of the inductor changes which makes the diode go to forward bias. Hence, the anode voltage becomes more positive than cathode during this period and starts conducting electricity. To find the transfer function of our circuit we need to consider steady state. The average voltage across the inductor is zero & the inductor will act as a short circuit in steady state to a pure DC. So, we find the output voltage is equal to the duty cycle multiplied by source voltage (V_O= DV_{DC}).

3.2.2 Components

Beside basic components our final design circuit consists of various electrical active and passive components. We have followed different methods, calculations and market availability to select components for our device. The list of components is given below:

Table 3.1: Components names and quantities

No.	Component Name	Quantity
1	Resistor	7
2	Capacitor	5
3	Inductor	1

4	Diode	2
5	Ceramic Capacitor	2
6	MOSFET (HY8290P)	1
7	PWM Controller (UC3845AN)	1
8	Phototransistor (FL817)	1
9	Shunt regulator (TL431A)	1
10	Schottky rectifier (STPS20S100CT)	1
11	Fuse	1
12	Heatsink	1
13	Copper clad board	1 lot
14	Connecting wires	1 lot

1. Resistor

We have selected through hole type carbon composition resistor resistors. A total of ten resistors was needed for our design with different values. Because of their strength and basic structure, as well as their capacity to absorb a great deal of energy in the form of pulses, carbon composition resistors are among the oldest and the most commonly used current carrying devices.

Figure 3.5: carbon composition resistor

Carbon composition resistors are made by combining carbon powder with a binder like ceramic or clay. The amount of binder relative to carbon determines the composition and therefore the resistive value of the carbon composition. The end caps are used to connect the resistive core to wires for current attachment, while the insulating coating protects the carbon from damage and electrical shorts. With a high surge capacity and power ratings, Carbon composition resistors serve the purpose of applications that need high current dispersion and surge protection. Because they are non-inductive, they are very useful for high frequency applications such as microwaves. Due to their wire wound and metal film counterparts, which have significantly higher accuracy, these have higher noise and lower precision.

Carbon composition resistors were widely used in older electronics, in circuits that have high pulse requirements or unless a low weight device that is strong enough to endure high energy was required. Nowadays, they are not that widely used because of the developments with resistors, but they are inexpensive and easy to manufacture. .

2. Capacitor

Through hole type polyester capacitors and electrolytic capacitors are used in our design. In any DC-DC converter capacitor plays a vital role and a core component of the full operation.

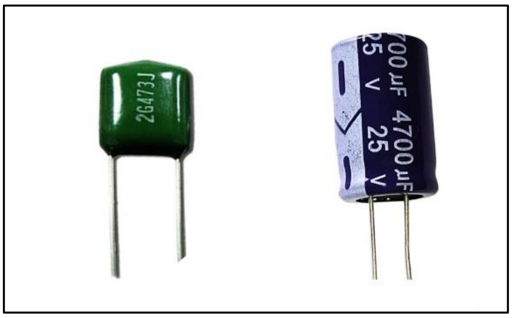

Figure 3.6: polyester capacitor (left) and electrolytic capacitor (right)

Capacitors are critical components in DC-DC buck converters, primarily serving to smooth the output voltage, reduce ripples, and enhance overall system stability. During the rapid switching cycles of the MOSFET, capacitors act as reservoirs, absorbing excess energy during peaks and supplying it during dips, thereby ensuring a steady DC output. They help maintain consistent voltage levels by filtering out high-frequency noise and minimizing the ripple effect, which is crucial for the reliable operation of sensitive electronic loads. Additionally, capacitors provide localized energy storage, reducing the demand on the input power source during transient load changes and improving the converter's efficiency. Their role in stabilizing voltage and current across the circuit is indispensable, making them essential for achieving high performance and reliability in buck converter designs.

Capacitor value calculation is a major part in our design. We have to determine the capacitor voltage that ensures that circuit operates as desired without damaging the capacitor. The maximum capacitor voltage (V_{Cmax}) must withstand the maximum voltage of the output. Which can be determine by $V_{Cmax} = V_O + \Delta V_O/2$ (ΔV_O is slope of output voltage).

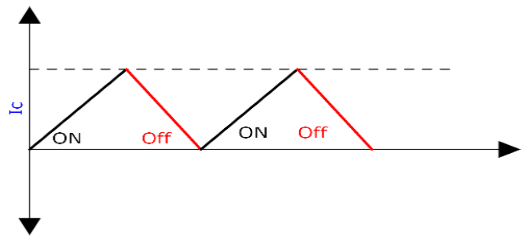

Figure 3.7: waveform of the capacitor current

Capacitor will provide a road way for ripples which will be produced by the inductor current while a pure DC current will flow by the output. Where the capacitor acts as a filter.

3. Inductor

One of the key component of our design is the inductor also in any DC-DC voltage conversion circuit. Critical inductance & peak current rating is how the inductor size is determined in any DC-DC buck converter. Critical inductance is the minimum value of inductance when inductor current reaches zero. The peak current rating of inductor is found by the maximum value of the inductive current which occurs at the maximum load.

Figure 3.8: Inductor

The inductance of an inductor in a buck converter is calculated based on the desired ripple current (ΔI_L), input voltage (V_{dc}), output voltage (V_O), switching frequency (f_S), and load current (I_O). We have calculated the value from the known formula to determine inductance.

$$L = \frac{V_{\text{out}} \cdot (1 - D)}{f_s \cdot \Delta I_L}$$

=12 (1-.25)100000 36=2.5 H

Primarily responsible for energy storage and current regulation. During the MOSFET's ON state, the inductor stores energy in its magnetic field by allowing current to increase linearly, while in the OFF state, it releases this energy to the load, ensuring continuous power delivery. This dual action helps smooth the current flow and reduces ripples, maintaining a steady output current despite the pulsed nature of the input.

4. Diode

This is a very common, essential and widely used component in most of the electrical devices. On a very basic level it controls the direction of the electrical current flow like a one way switch.

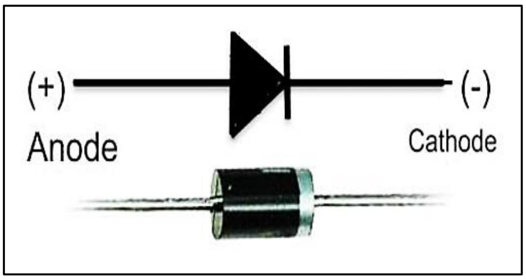

Figure 3.9: Diode

The diode in a DC-DC buck converter plays a critical role in ensuring the continuous flow of current to the load during the switching cycle. When the MOSFET switch is off, the inductor's stored energy maintains current flow, but without a diode, this current would have no return path, leading to interruptions and potential circuit instability. The diode provides this necessary path by becoming forward-biased when the switch turns off, allowing the inductor to discharge its energy smoothly to the load. This action not only prevents voltage spikes and current disruptions but also protects the circuit components from damage caused by sudden changes in current. Additionally, the diode helps in maintaining the output voltage during the off-state, contributing to the overall efficiency and stability of the buck converter. Diodes are often preferred for their low forward voltage drop and high-speed operation, further enhancing the performance of the converter.

5. MOSFET

It is the key switching element in a DC-DC buck converter, enabling the regulation of output voltage by controlling the flow of energy from the input to the load. As a high-speed switch, the MOSFET alternates between on and off states based on the control signal, determining the duty cycle, which directly influences the output voltage. When the MOSFET is on, it allows energy to flow to the inductor and load, and when off, it facilitates energy transfer from the inductor to the load through the diode.

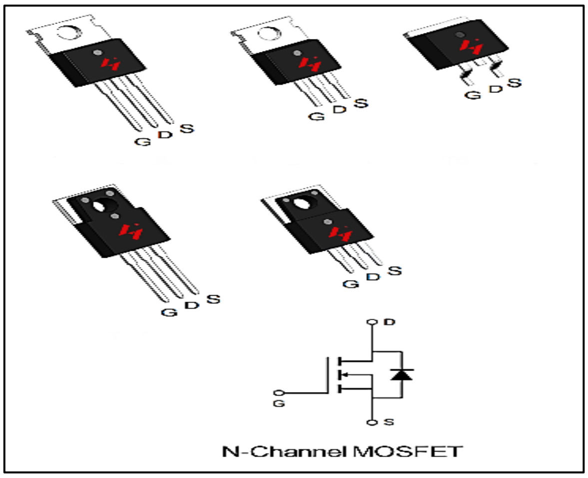

Figure 3.10: MOSFET

Additionally, modern MOSFETs are designed for high-frequency operation, which reduces the size of passive components like inductors and capacitors, making the converter more compact and cost-effective. The MOSFET's fast switching speed and ability to handle high currents make it indispensable for the reliable and efficient performance of buck converters. They can come in many sizes and shapes typically known as packages. For our design we have selected HY8290P MOSFET "HY" is the available brand name it's an N-channel MOSFET.

Table 3.2: Absolute maximum ratings of the HY9280P MOSFET

Symbol	Parameter		Rating	Unit
Common Ratings (T_C=25°C Unless Otherwise Noted)				
V_{DSS}	Drain-Source Voltage		80	V
V_{GSS}	Gate-Source Voltage		±25	
T_J	Maximum Junction Temperature		175	°C
T_{STG}	Storage Temperature Range		-55 to 175	°C
I_S	Diode Continuous Forward Current	T_C=25°C	94	A
Mounted on Large Heat Sink				
I_{DM}	Pulsed Drain Current *		330**	A
I_D	Continuous Drain Current	T_C=25°C	94	A
		T_C=100°C	64	
P_D	Maximum Power Dissipation	T_C=25°C	150	W
		T_C=100°C	75	
$R_{\theta JC}$	Thermal Resistance-Junction to Case		1	°C/W
$R_{\theta JA}$	Thermal Resistance-Junction to Ambient		62.5	
Avalanche Ratings				
E_{AS}	Avalanche Energy, Single Pulsed	L=0.5mH	360***	mJ

The reason behind selecting this particular MOSFET is due to its higher D-S voltage limit and low internal resistance.

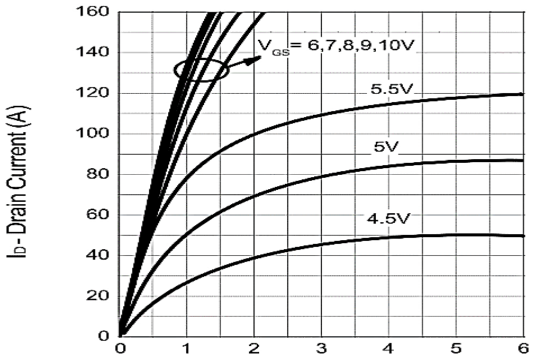

Figure 3.11: V-I Curve of the MOSFET

It has three main terminals: gate, drain, and source. When a positive voltage is applied to the gate relative to the source, it generates an electric field that attracts electrons to the region just below the gate oxide in the semiconductor substrate, forming a conductive channel between the drain and source. This channel allows current to flow from the drain to the source when a voltage is applied across them.

Table 3.3: Electrical characteristics of the 8290 MOSFET

Symbol	Parameter	Test Conditions	HY8290			Unit
			Min.	Typ.	Max.	
Static Characteristics						
BV_{DSS}	Drain-Source Breakdown Voltage	V_{GS}=0V, I_{DS}=250μA	80	-	-	V
I_{DSS}	Zero Gate Voltage Drain Current	V_{DS}=80V, V_{GS}=0V	-	-	1	μA
		T_J=85°C	-	-	10	
$V_{GS(th)}$	Gate Threshold Voltage	V_{DS}=V_{GS}, I_{DS}=250μA	2	3	4	V
I_{GSS}	Gate Leakage Current	V_{GS}=±25V, V_{DS}=0V	-	-	±100	nA
$R_{DS(ON)}$*	Drain-Source On-state Resistance	V_{GS}=10V, I_{DS}=47A	-	7.2	8.5	mΩ
Diode Characteristics						
V_{SD}*	Diode Forward Voltage	I_{SD}=47A, V_{GS}=0V	-	0.8	1	V
t_{rr}	Reverse Recovery Time	I_{SD}=47A, dI_{SD}/dt=100A/μs	-	62	-	ns
Q_{rr}	Reverse Recovery Charge		-	123	-	nC
Dynamic Characteristics						
R_G	Gate Resistance	V_{GS}=0V,V_{DS}=0V,F=1MHz	-	1.5	-	Ω
C_{iss}	Input Capacitance	V_{GS}=0V, V_{DS}=25V, Frequency=1.0MHz	-	5000	-	pF
C_{oss}	Output Capacitance		-	330	-	
C_{rss}	Reverse Transfer Capacitance		-	230	-	
$t_{d(ON)}$	Turn-on Delay Time	V_{DD}=40V, R_G = 6 Ω, I_{DS} =47A, V_{GS}=10V,	-	40	-	ns
T_r	Turn-on Rise Time		-	55	-	
$t_{d(OFF)}$	Turn-off Delay Time		-	68	-	
T_f	Turn-off Fall Time		-	36	-	
Gate Charge Characteristics						
Q_g	Total Gate Charge	V_{DS}=64V, V_{GS}=10V, I_{DS}=47A	-	96	-	nC
Q_{gs}	Gate-Source Charge		-	23	-	
Q_{gd}	Gate-Drain Charge		-	33	-	

In the absence of a gate voltage, the channel does not form, and the MOSFET remains off, effectively blocking current flow. The N-channel MOSFET is preferred in many applications due to its lower on-resistance and higher efficiency compared to P-channel MOSFETs, especially in high-current scenarios.

6. PWM Controller

A PWM (Pulse Width Modulation) controller in a buck converter is responsible for regulating the output voltage by controlling the duty cycle of the switching element, typically a MOSFET. The PWM controller adjusts the ratio of the ON time to the OFF time of the MOSFET in response to changes in input voltage or load demand. By modulating the duration of the MOSFET's ON state, the PWM controller determines how much energy is delivered to the inductor and subsequently to the load. A higher duty cycle (longer ON time) results in more energy transfer, increasing the output voltage, while a lower duty cycle (shorter ON time) decreases the energy transfer, lowering the output voltage.

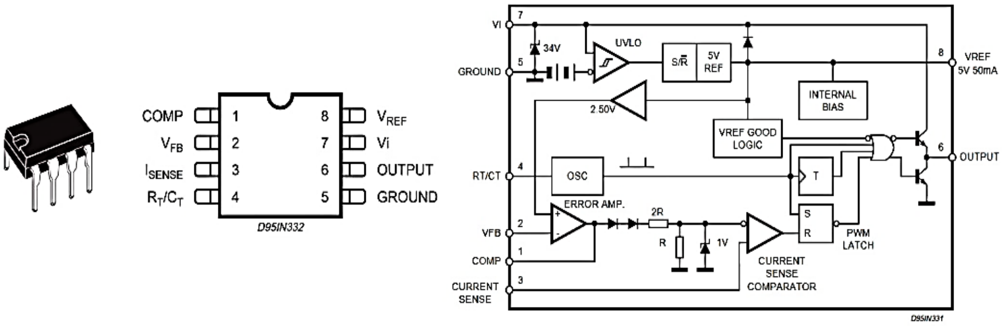

Figure 3.12: PWM controller UC3845AN

The controller typically uses feedback from the output voltage through a voltage divider and compares it to a reference voltage to ensure accurate regulation.

Table 3.4: Pin function of the PWM controller

N°	Pin	Function
1	COMP	This pin is the Error Amplifier output and is made available for loop compensation.
2	V_{FB}	This is the inverting input of the Error Amplifier. It is normally connected to the switching power supply output through a resistor divider.
3	I_{SENSE}	A voltage proportional to inductor current is connected to this input. The PWM uses this information to terminate the output switch conduction.
4	R_T/C_T	The oscillator frequency and maximum Output duty cycle are programmed by connecting resistor R_T to V_{ref} and cpacitor C_T to ground. Operation to 500kHz is possible.
5	GROUND	This pin is the combined control circuitry and power ground.
6	OUTPUT	This output directly drives the gate of a power MOSFET. Peak currents up to 1A are sourced and sunk by this pin.
7	V_{CC}	This pin is the positive supply of the control IC.
8	V_{ref}	This is the reference output. It provides charging current for capacitor C_T through resistor R_T.

Additionally, the PWM controller helps maintain efficiency by operating the MOSFET in its fully ON or OFF states, minimizing power losses. It also supports protection features like overcurrent, overvoltage, and thermal shutdown, ensuring the converter operates safely under varying conditions. In essence, the PWM controller is the brain of the buck converter, enabling precise voltage regulation, high efficiency, and adaptability to changing electrical demands.

7. Phototransistor

Phototransistor is used for isolation in a buck converter as part of an optocoupler circuit, providing electrical isolation between the high-voltage or high-current side (primary side) and the low-voltage control side (secondary side). This isolation is crucial for protecting sensitive control circuitry from potentially damaging voltage spikes, noise, or surges. The phototransistor works by converting light signals into electrical signals, effectively breaking the direct electrical connection between the two sides. In a typical setup, an LED on the primary side emits light when driven by a control signal.

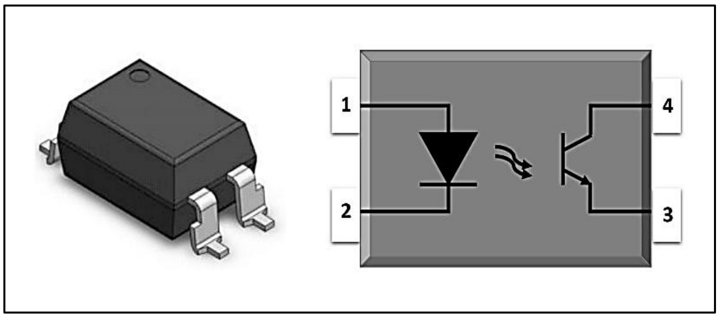

Figure 3.13: Phototransistor and its schematic diagram.

This light travels across an insulating gap and falls on the phototransistor on the secondary side. The phototransistor, which is photosensitive, becomes conductive in response to the light, allowing current to flow through its terminals. This current is used to drive subsequent control or feedback mechanisms in the buck converter. The phototransistor's sensitivity and speed ensure that changes in the control signal are accurately and rapidly transmitted while maintaining isolation. This method of isolation not only enhances the safety and reliability of the system but also minimizes the risk of ground loops and electromagnetic interference (EMI). In high-frequency buck converters, phototransistors are preferred due to their ability to handle fast switching signals, ensuring precise control and regulation of the converter's operation. This design is widely adopted in industrial and consumer power supplies where robust isolation and efficient operation are required.

8. Shunt regulator

A shunt regulator in a buck converter is used to maintain a stable reference voltage by shunting excess current away from the load to ground when the voltage exceeds a specified level. It operates as a voltage-clamping device, ensuring that the output voltage remains within a desired range even under varying input voltages or load conditions. In a buck converter, the shunt regulator is typically employed as part of the feedback control circuit, often to provide a precise reference voltage for the PWM controller or other control components.

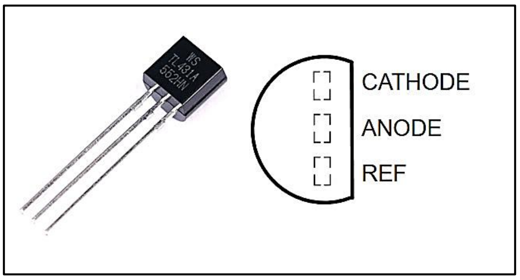

Figure 3.14: Shunt regulator.

The shunt regulator works by presenting a very high impedance under normal operating conditions, allowing most of the current to flow to the load. However, when the output voltage rises above the regulator's set point, it reduces its impedance and diverts the excess current to ground, thereby preventing overvoltage at the output. This regulation helps protect sensitive downstream components from voltage fluctuations, improving the overall stability and reliability of the buck converter.

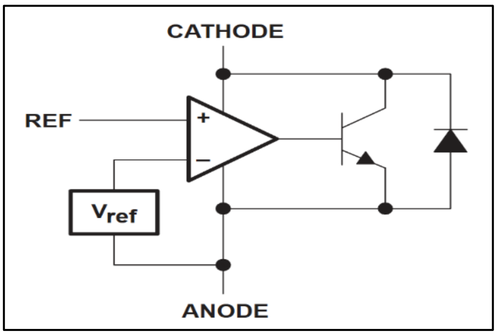

Figure 3.15: Functional Block Diagram of a shunt regulator.

Shunt regulators are commonly realized using Zener diodes for simple designs or more complex integrated circuits for higher precision and performance. While they are not typically used for high-current regulation due to potential energy losses, their simplicity and effectiveness in low-power applications or as voltage references make them a useful addition in certain buck converter designs.

9. Schottky Rectifier

A Schottky rectifier plays a critical role in a buck converter by providing a low-loss freewheeling path for the inductor current when the MOSFET switch is turned off. It is a type of diode characterized by its low forward voltage drop (typically 0.2–0.4 V compared to 0.7 V in standard silicon diodes), which minimizes power losses and improves the efficiency of the converter.

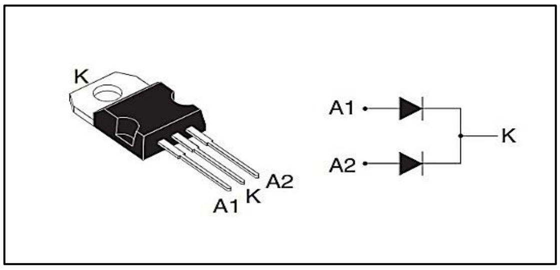

Figure 3.16: Schottky rectifier

In the operation of a buck converter, when the MOSFET is off, the inductor's energy must continue to flow to the load to maintain a continuous current. The Schottky rectifier becomes forward-biased in this phase, allowing the current to flow through it. Its fast switching capability ensures minimal delay in providing the conduction path, which is essential for high-frequency operation. Additionally, its lower reverse recovery time reduces switching losses and prevents voltage spikes, contributing to the smooth operation of the converter.

Table 3.5: Absolute ratings of the Schottky rectifier (STPS20S100CT)

Symbol	Parameter				Value	Unit
V_{RRM}	Repetitive peak reverse voltage				100	V
$I_{F(RMS)}$	Forward rms current				30	A
$I_{F(AV)}$	Average forward current δ = 0.5	TO-220AB / I^2PAK	T_c = 150 °C	Per diode Per device	10 20	A
		TO-220FPAB	T_c = 140 °C	Per diode Per device	10 20	
I_{FSM}	Surge non repetitive forward current		t_p = 10ms sinusoidal		180	A
P_{ARM}	Repetitive peak avalanche power		t_p = 1µs T_j = 25 °C		7200	W
T_{stg}	Storage temperature range				-65 to + 175	°C
T_j	Maximum operating junction temperature (1)				175	°C
dV/dt	Critical rate of rise of reverse voltage				10000	V/µs

Due to its ability to handle high currents and operate efficiently at high switching speeds, the Schottky rectifier is particularly suited for modern compact and low-voltage buck converters used in power supplies, battery chargers, and other electronic devices. Its contribution to reducing heat generation and enhancing efficiency makes it a preferred choice in many power electronics designs.

3.3 Design Specifications

The buck converter developed in this project was designed with specific criteria to meet the energy demands of DC solar home systems. The design specifications were carefully established to ensure efficient performance, reliability, and adaptability for powering a wide range of DC electrical appliances commonly used in such systems. Below a flow chart is given of the process.

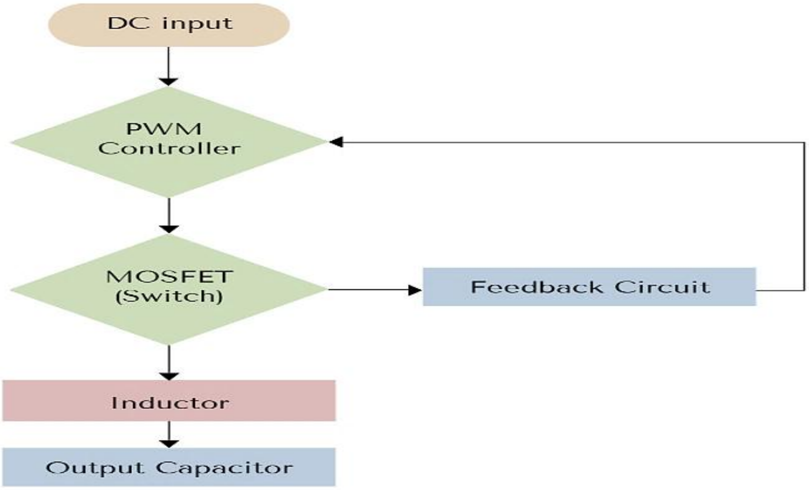

Figure 3.16: Block Diagram of DC Electrical Appliances

3.3.1 Input Voltage

The buck converter is designed to operate with an input voltage range of 24V to 48V DC, which aligns with typical voltage levels in solar battery systems. This wide range ensures compatibility with various solar setups and accommodates voltage fluctuations that may occur due to battery charging or discharging cycles.

3.3.2 Output Voltage

The converter provides two types of outputs:

1. **Fixed Output:** A regulated 12V DC output, designed to power standard DC appliances such as LED lights, fans, and small electronics. This output ensures stable and consistent performance for appliances requiring a fixed voltage.

2. **Variable Output:** An adjustable DC output ranging from 5V to 48V, intended for appliances with diverse voltage requirements. This flexibility reduces the need for multiple converters and enhances system efficiency.

3.3.3 Output Current

The converter is designed to handle a maximum load current of 20A for the 12V output and 10A for the variable output. This ensures sufficient power delivery for multiple appliances operating simultaneously.

3.3.4 Control and Regulation

A PWM controller regulates the switching of the MOSFET, ensuring precise voltage control and stable outputs under varying load conditions. The feedback mechanism allows real-time adjustments, maintaining optimal performance.

3.3.5 Key Components

- **MOSFET:** High-efficiency N-channel MOSFET for switching operations.
- **Inductor:** High-current inductor to smooth the output current.
- **Capacitors:** Electrolytic and ceramic capacitors for reducing ripple and noise.
- **Diode:** Schottky diode for fast switching and reduced power losses.
- **Heat Dissipation:** Integrated heatsinks for effective thermal management.

3.3.6 PCB Design

The PCB was designed using EasyEDA, incorporating a compact and modular layout to ensure ease of installation and scalability. The design minimizes parasitic elements and optimizes component placement for improved performance and reduced electromagnetic interference (EMI).

3.3.7 Application Scope

This buck converter is specifically tailored for DC solar homes, enabling efficient power distribution to appliances such as DC lights, fans, refrigerators, and other electronics. Its ability to support both fixed and variable outputs makes it a versatile and cost-effective solution for off-grid energy systems.

3.4 Summary

This study focuses on the design, development, and testing of a buck converter tailored for DC solar home systems, aimed at efficiently powering DC electrical appliances with varying voltage requirements. The buck converter was meticulously designed using EasyEDA software to ensure a compact and optimized printed circuit board (PCB) layout. The converter operates with an input voltage range of 24-48 V DC, sourced from a solar battery, and delivers multiple fixed 12V outputs alongside a variable output voltage. This dual-output feature is a significant innovation, allowing the system to power a diverse range of DC appliances without requiring separate converters for each voltage level.

The converter's design incorporates key components, including a high-efficiency MOSFET, an inductor, a Schottky diode, and capacitors, all optimized for minimal power losses and heat generation. Advanced control circuitry ensures precise regulation of the output voltages, maintaining system stability and performance under varying load conditions. An onboard PWM controller manages the switching operation of the MOSFET, ensuring efficient energy conversion while minimizing ripple and noise in the outputs.

The primary motivation behind this development was to create a one-device solution for DC solar homes, eliminating the need for multiple converters and reducing system complexity. The final design was extensively tested, confirming its ability to handle input voltage variations and provide reliable, regulated outputs. The results demonstrate the converter's potential to enhance the efficiency and practicality of DC solar home systems, offering a cost-effective and energy-efficient solution for powering a wide range of household appliances. This research contributes to the advancement of renewable energy applications by simplifying energy management in off-grid solar setups, aligning with global efforts to promote sustainable energy solutions.

CHAPTER 4
PROJECT MANAGEMENT

4.1 Task, Schedule and Milestones

The project followed a structured and phased approach to ensure its successful completion. It began with an analysis of requirements and an extensive review of relevant literature, laying a solid foundation for the design process. This was followed by the system design and simulation phase, where tools like EasyEDA were utilized to develop precise circuit layouts and achieve the desired specifications. Each step was aligned with the overarching goal of creating a multi-output DC-DC buck converter for off-grid solar-powered homes.

Procurement of components, such as the HY8290P MOSFET and UC3845AN PWM controller, posed challenges due to availability constraints. However, timely adjustments in procurement strategies ensured that all required materials were acquired. Prototype development involved assembling components and creating PCB layouts designed for optimal efficiency and performance. The testing and optimization phase validated the converter's functionality under varying load conditions, confirming its compliance with efficiency and voltage regulation goals.

Although initial scheduling anticipated quicker procurement, adjustments were made to accommodate delays without compromising the quality of deliverables. Overall, the milestones were achieved as planned, ensuring project success.

4.2 Resources and Cost Management

Resource management was a pivotal aspect of this project, ensuring optimal utilization of available resources while adhering to budgetary constraints. The procurement phase prioritized high-quality, cost-effective components. Bulk purchases and local sourcing minimized expenses while maintaining quality. By leveraging simulation tools like EasyEDA, the design phase reduced the likelihood of costly prototyping errors.

Access to the renewable energy lab played a crucial role in minimizing external resource requirements. The lab provided essential testing equipment, enabling the evaluation of the prototype under real-world conditions. Continuous budget monitoring ensured all expenditures aligned with the financial plan. Minor adjustments, such as reallocating funds for additional capacitors to enhance performance, were effectively managed to keep the project within budget.

This systematic approach to resource and cost management underscored the importance of strategic planning and flexibility in achieving project objectives while maintaining financial efficiency.

4.3 Lesson Learned

Conducting this project offered numerous valuable lessons in managing technical tasks and coordinating resources. Planning was integral to the process, but adaptability emerged as equally important in addressing unforeseen challenges like procurement delays. These experiences reinforced the need for proactive problem-solving and strategic decision-making.

From a technical perspective, the project significantly enhanced expertise in designing and optimizing DC-DC buck converters. Understanding the interplay between components such as MOSFETs, capacitors, and inductors proved critical in achieving efficiency and reliability. Prototyping and iterative testing highlighted the importance of validating designs under practical conditions to ensure optimal performance.

Moreover, the project emphasized the value of resource optimization and teamwork. Effective collaboration with suppliers and within the team facilitated smooth execution, while clear communication and coordination ensured challenges were promptly addressed. These lessons will serve as a foundation for future technical endeavors, demonstrating the importance of balancing technical knowledge, resource management, and adaptability.

CHAPTER 5
IMPACT ASSESSMENT OF THE PROJECT

5.1 Economical, Societal and Global Impact

The project has far-reaching implications at the economic, societal, and global levels. Economically, this solution reduces the need for multiple converters, lowering system costs for homeowners and making solar-powered systems more accessible. By optimizing energy efficiency and reducing operational expenses, the converter promotes cost savings for end users. Furthermore, the project’s scalable design encourages local manufacturing, potentially fostering employment opportunities in the renewable energy sector.

From a societal perspective, the converter directly impacts energy accessibility by enabling the efficient utilization of solar power in off-grid areas, improving the quality of life for underserved populations. Reliable power for lighting, appliances, and other essentials enhances educational, health, and economic opportunities in remote communities. Globally, the project aligns with efforts to transition toward renewable energy sources, contributing to a reduction in carbon emissions and advancing the fight against climate change.

Additionally, by simplifying system architecture and lowering energy wastage, the converter indirectly supports the development of resilient infrastructure and promotes sustainable energy practices, which are critical for achieving global energy goals.

5.2 Environmental and Ethical Issues

The project was designed with environmental sustainability at its core. By improving the efficiency of DC systems and reducing energy losses, it minimizes the carbon footprint of off-grid solar installations. The compact and integrated design reduces the material and energy required for production, indirectly supporting waste reduction.

In terms of environmental aesthetics, the project's contribution to cleaner energy usage helps decrease reliance on polluting energy sources like diesel generators, promoting cleaner air and a healthier environment.

No significant ethical issues were identified during the project. However, the team adhered to ethical responsibilities by ensuring that all components were sourced responsibly and that the design promoted energy conservation. The project aligns with ethical engineering practices by prioritizing safety, sustainability, and accessibility for marginalized communities

5.3 Utilization of Existing Standards or Codes

The project adhered to widely recognized standards and codes to ensure safety and compatibility. Key considerations included:

- Electrical Safety Standards: The converter design complies with IEC 61558 for the safety of power transformers and other similar devices, ensuring robust insulation and protection against electrical hazards.
- EMI/EMC Compliance: Measures were implemented to reduce electromagnetic interference, ensuring the device complies with CISPR 11 and related standards.
- Energy Efficiency Standards: The design aligns with energy efficiency guidelines to maximize output with minimal energy losses, supporting sustainable energy use.
- PCB Design Standards: Best practices in PCB design were followed, including IPC-2221 guidelines, to ensure reliable circuit performance and manufacturability.
- Sustainability Standards: Efforts were made to align the project with ISO 14001 guidelines for environmental management systems, reducing its ecological impact.

These standards ensured that the project was safe, efficient, and compatible with global regulations, paving the way for its practical deployment.

5.4 Other Concerns

No additional issues were encountered during the project's development. However, as with any new technology, ongoing monitoring and refinement are recommended to ensure that the design remains compatible with evolving technological standards and user needs. Future iterations may also explore additional features, such as enhanced automation or IoT integration, to further improve functionality and user experience.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The project successfully achieved its goal of designing and developing a multi-output DC-DC buck converter optimized for off-grid solar-powered homes. The converter efficiently handled input voltages ranging from 24 V to 48 V DC, delivering two distinct outputs: a fixed 12 V DC for standard low-voltage appliances and a variable DC output adaptable to diverse voltage requirements. Testing confirmed that the design met all major specifications, including high efficiency, stable voltage regulation, and adaptability across varying load conditions.

The integration of advanced components, such as the HY8290P MOSFET and UC3845AN PWM controller, played a critical role in ensuring reliable operation and minimizing energy losses. The converter demonstrated excellent performance in maintaining output voltage stability, even under dynamic load changes. This achievement addresses key challenges in DC-powered homes, particularly the need to eliminate the reliance on multiple converters for different appliances, thereby simplifying system architecture and reducing costs.

The final design showcases strong potential for practical application in off-grid solar systems, contributing to energy efficiency and system reliability. Beyond residential use, this converter has promising applications in industrial settings, portable energy systems, and renewable energy integration projects, particularly in scenarios requiring compact, multi-voltage solutions.

This work significantly contributes to advancing DC-based renewable energy systems by providing a streamlined solution for managing voltage requirements. It highlights the importance of efficiency, adaptability, and simplicity in promoting the adoption of renewable energy technologies in underserved and remote regions.

6.2 New Skills and Experiences Learned

This project provided an excellent opportunity to acquire and refine several technical and managerial skills. Key technical competencies included mastering the design and optimization of DC-DC converters, particularly in selecting and integrating components like MOSFETs, inductors, and PWM controllers. Hands-on experience with simulation tools, such as EasyEDA, enhanced circuit design and PCB layout skills.

The prototyping phase offered practical insights into assembling and troubleshooting electronic circuits, while the testing process deepened understanding of voltage regulation, load adaptation, and efficiency improvement. Beyond technical skills, this project fostered effective resource management, budget planning, and problem-solving abilities. Collaboration with team members and suppliers also strengthened communication and coordination skills, emphasizing the importance of teamwork in project execution.

6.3 Future Recommendations

While the project successfully achieved its objectives, several areas offer scope for future enhancement. First, integrating advanced wide-bandgap semiconductors, such as SiC or GaN devices, could further improve efficiency and thermal performance. These components could also enable operation at higher switching frequencies, reducing the size of passive components like inductors and capacitors.

Second, implementing intelligent control systems, such as microcontrollers or digital signal processors, could add features like dynamic voltage adjustment, fault detection, and remote monitoring. This would enhance the converter's usability and make it more versatile for various applications.

Lastly, expanding the design to accommodate higher input voltage ranges and multiple variable outputs could increase the system's scalability for industrial and commercial applications. Future research could also explore integrating energy storage solutions to make the converter more suitable for hybrid systems combining solar power and batteries.

These recommendations highlight potential avenues for improving the project's functionality and applicability, ensuring it remains at the forefront of innovation in renewable energy systems.

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APPENDIX A

TURNITIN REPORT

ORIGINALITY REPORT

17%	13%	6%	8%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

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APPENDIX B

COMPLEX ENGINEERING PROBLEM SOLVING AND ENGINEERING ACTIVITIES

Complex Engineering Problems (P) Solving		
	Attributes	Statement from students
P1	Depth of knowledge required	The project required an in-depth understanding of power electronics, including the design and optimization of DC-DC buck converters. Concepts like PWM control, MOSFET switching, and inductor-capacitor filtering were applied to ensure system efficiency and reliability.
P2	Range of conflicting requirements	Balancing the converter's dual-output requirements for fixed and variable voltages posed conflicting challenges. Ensuring cost efficiency, high performance, and compatibility with varying load conditions were critical considerations.
P3	Depth of analysis required	Comprehensive simulations using EasyEDA were conducted to analyze the converter's behavior under different load and input conditions, ensuring stable voltage regulation and minimal energy loss.
P4	Familiarity of issues	Addressed the common issues in DC-powered homes, such as voltage instability and the need for multiple converters. This project aimed to simplify the system architecture by integrating multi-output functionality.
P5	Extent of applicable codes	Adherence to IEC 61558 for safety, IPC-2221 for PCB design, and ISO 14001 for environmental sustainability ensured compliance with industry standards.
P6	Extent of stakeholder involvement and conflicting requirements	Stakeholders included off-grid homeowners and renewable energy advocates. Their needs for affordability, reliability, and simplicity were integrated into the design.
P7	Interdependence	The project involved an interplay of multiple engineering disciplines, including circuit design, thermal management, and component selection, to achieve a cohesive and effective solution.

Complex Engineering Problems (P) Solving		
	Attributes	Statement from students
A1	Range of resources	Utilized a combination of software tools (EasyEDA), high-quality components (e.g., MOSFETs, Schottky rectifiers), and lab facilities for prototyping and testing.
A2	Level of interaction	Involved active collaboration among team members, guidance from supervisors, and communication with component suppliers to overcome challenges.
A3	Innovation	Designed a novel multi-output DC-DC converter capable of addressing the unique voltage requirements of DC-powered homes while improving energy efficiency.
A4	Consequences of society and environment	The project contributes to reducing carbon emissions by enhancing the efficiency of renewable energy systems. It also provides energy solutions for underserved communities.
A5	Familiarity	Gained familiarity with industry standards, advanced design techniques, and practical challenges in implementing energy-efficient solutions.