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ASSIGNMENT 1: PAPER DESIGN

EEE3098S 2023

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Table of Contents

Introduction

Consider an industrial automation setup where a specific component such as a motor control requires a low voltage between the range 5 to 9 Volts to operate. However, this industrial facility only has access to line voltage which is 220 Volts rms.

Hence the task ahead is to design a Switched-Mode Power Supply (SMPS) that regulates the line voltage down to the range of 5 to 9 Volts. This design will consist of a rectification from AC to DC then step the voltage down using a Buck converter to the desired voltage range.

Furthermore, the efficiency of the Switched-Mode Power Supply/buck converter will be measured using an I2C digital wattmeter and the UCT STM32F051C6T6

Requirement Analysis

Interpretation of the requirements:

This design task is a Switched-Mode Power Supply. However, this can be broken down into sub-modules in order to break down and detail the requirements clearly.

Requirement ID	Requirement name	Detail
RID001	AC to DC rectification	The device will have to rectify an AC voltage of 220 Volts rms into a constant DC Voltage which will be approximately 20 Volts that will be fed into the buck converter.
RID002	DC to DC converter	A Buck Converter will be needed in order to drop the 20 Volts into the desired 5 to 9 Volts range which will then be used to supply the component of interest such as the motor controller.
RID003	Microcontroller and Wattmeter	The SMPS will also be required to calculate the efficiency of the converter. This is where the I2C digital wattmeter and the UCT STM32F051C6T6 will be used to do that.

In essence, the full design should be able to rectify AC to DC, then step the high voltage down to the desired range of 5 to 9 Volts. Furthermore, the design should incorporate the measurement of the efficiency of the step-down converter.

Types of converters and structures in the converter needed:

This design task is a Switched-Mode Power Supply. However, this can be broken down into sub-modules in order to break down and detail the types of converters and structures needed in the SMPS design.

1. AC to DC rectification (RID001) – The rectification process can be seen as a fairly simple stage of the SMPS. It will consist of four Schottky diodes and a smoothing capacitor. The rectifier circuit will follow the **bridge rectifier topology**. The schematic of this rectifier can be found under the Subsystem Design subheading.
2. DC to DC converter (RID002) – A **buck converter** will be used at this stage in order to step down the voltage from the 15 Volts down to the 5 to 9 Voltage range. This converter will consist of a Schottky diode, inductor, capacitor and a switch. The schematic of this converter can be found under the Subsystem Design subheading.
3. Microcontroller and Wattmeter (RID003) – This submodule will be largely to do with the operation of the microcontroller and its integration into the SMPS. The I2C Wattmeter will be connected across the load and will be used to determine the efficiency of the buck converter.

Feasibility analysis:

In order for the design to be successful, the design process needs to be well feasible. The feasibility can be maximised in the following ways:

- Efficiency: In order to maximise the efficiency of the design process flow, the overall design has been split into submodules which makes the distribution of workload easier and the completion of the work more quickly.
- Budget: Through smart use of devices, such as recycling the STM32F051C6T6, we will be able to drop the overall price of the SMPS which in turn increase the likeliness of a profit being made.
- Implementation: Microsoft teams was used for communication of ideas within the team to be shared easily, to avoid confusion and lead to faster solutions to issues. The team will also work together in the construction of the device speeding up the process.
- Demand: The device serves as an answer to a very crucial and needed problem faced in industrial fields. Therefore, the demand for the device will be high.

The points above show the good feasibility of the design and production of the SMPS.

Possible bottlenecks:

There could be various bottlenecks along the way that could hinder the flow of the design process and the production of the SMPS. These bottlenecks could be as follows:

- Lack of knowledge using Simulink – Learning the ins and outs of Simulink might take some time.
- Time limitations – Due to the short time period before the deadline, certain parts of the design might be rushed.

- Resource bottleneck – There will be limited components acquired hence those components can't get damaged otherwise it will hinder the flow of production and implementation.
- Budget – We do not have unlimited funds hence the design must be as cost friendly as possible.

Subsystem Design

For this section, design considerations for the different subsystems of the SMPS will be outlined and these considerations are developed to ensure that each subsystem fulfills its specific requirements. The two subsystems are as follows:

1. **DC to DC – Buck Converter**

Requirements:

Requirement ID	Requirement name	Detail
RID002-1	Voltage Conversion	The primary requirement is to provide a regulated output voltage of 5V, with the added capability to switch between 5V and 9V as needed.
RID002-2	Efficiency	The buck converter must ensure a minimum of at least 80% efficiency.
RID002-3	Voltage ripple	The voltage ripple must be within acceptable limits, ideally as low as 100mV.

Specifications:

Specification ID	Specification name	Detail
RID002-S-1	Inductor	A 75 µH inductor will be employed, chosen for its ability to handle the maximum load current and avoid saturation.
RID002-S-2	Capacitor	A 68 µF capacitor will be used for smoothing and reducing voltage ripple, selected with a voltage rating higher than the maximum output voltage
RID002-S-3	Diodes	Schottky Diodes will be used.

RID002-S-4	MOSFET	A MOSFET with low RDS (on), along with suitable voltage and current ratings, will be selected to handle the input power efficiently.

<u>Selection of circuit topology:</u>

For this project, it is required that the designed system is efficient and can switch between different output voltages efficiently, and that is 5V and 9V. So, with that said, a step-down converter will be used due to its superior efficiency.

<u>Selection of circuit parameter:</u>

To explain how the selection of parameters occurred we will need to have a scenario/problem.

Let's consider a scenario where we aim to design an SMPS that converts a 20V DC input to a stable 5V DC output. The power requirement for this application is 5W, and we've chosen a switching frequency of 100 kHz. In addition, we want to maintain a current ripple of 0.5 and a voltage ripple of 10 mV for optimal performance.

$$Ripple\ current = \Delta i_L = 0.5\ A$$

$$Therefore\ to\ find\ Inductor\ Value:$$

$$L = \frac{V_0(1-D)}{f_s \Delta i_L}$$
$$Where:$$
$$V_0 = 5V$$
$$D = \frac{V_o}{V_{in}} = \frac{5}{20} = 0.25$$
$$f_s = 100kHz$$

$$Therefore\ from\ above\ the\ inductor\ value\ can\ be\ calculated:$$

$$L = \frac{5(1-0.25)}{(1000000)(0.5)} = 75\mu H$$

$$Capacitor\ value\ is\ calculated\ using:$$

$$C = \frac{1-D}{8L\left(\frac{\Delta V_o}{V}\right)f^2} = \frac{1-0.25}{8(75\mu)\left(\frac{0.01}{5}\right)(100000)^2} = 62.5\mu F$$

Now our selection:

- Inductor value 75 μH
- Capacitor value 68 $\mu F (aligned\ with\ standard\ E12\ value)$

2. Microcontroller and Wattmeter

To achieve an effective output the switch which will be the MOSFET will be interfaced with the Microcontroller through a gate drive which will enable the MOSFET to be operated since the output voltage of the microcontroller is 5V. The buck convertor will require high frequency switching and the value is depending on the selected values of the inductors and capacitors.

Requirements:

Requirement ID	Requirement name	Detail
RID003-1	PWM signal	Must be programmed in a way that is outputs a PWM signal with a high at 5V and low at 0V as seen below in figure 1.
RID003-2	Duty Cycle	The output should be variable from 5V or 9V thus microcontroller must be programmed to vary the frequency thus varying the duty cycle leading to a change in the output voltage.
RID003-3	Load Management	Provide feedback mechanisms to ensure load management.
RID003-4	Efficiency	Provide feedback mechanisms to monitor efficiency.

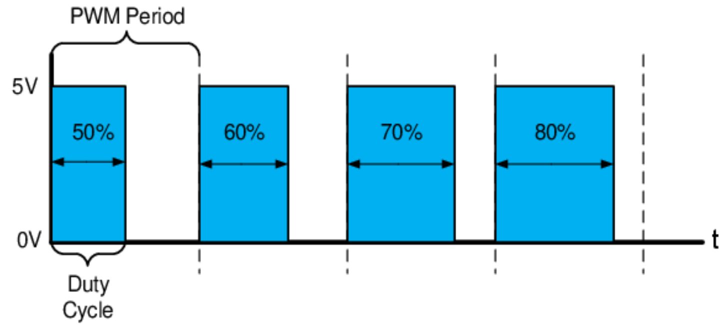


Figure 1:PWM with different Duty Cycles

Specifications:

The project has 3 essential blocks which include the rectification, filtering, and DC to DC conversion. Out of these three essential blocks the one utilizing the microcontroller is the DC-to-DC convertor.

Specification ID	Specification name	Detail
RID003-S-1	Wattmeter	I2C Wattmeter for feedback and efficiency monitoring
RID003-S-2	MOSFET Driver	MOSFET Gate driver for MCU interfacing
RID003-S-3	Output Voltage	Variable output voltage of 5 or 9 V.
RID003-S-4	Code	STMCube will be used.

Selection of circuit topology:

The SMPS need to be connected to the I2C wattmeter which can measure voltage, current, and power. The wattmeter will be interfaced between the microcontroller and the DC-DC convertor which will provide a feedback mechanism to the SMPS.

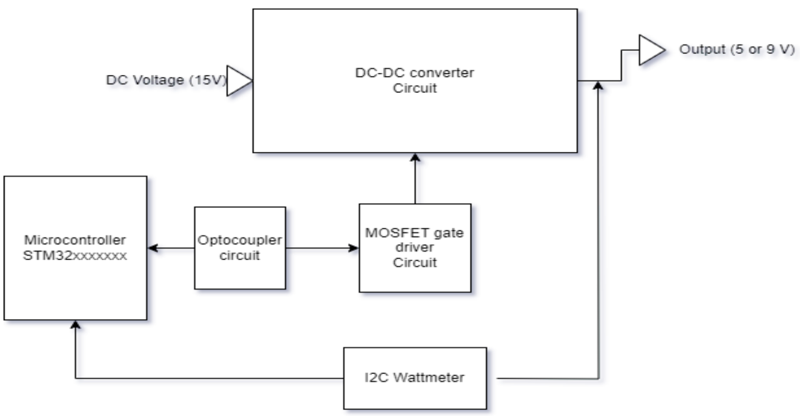


Figure 2:Blocked Diagrams

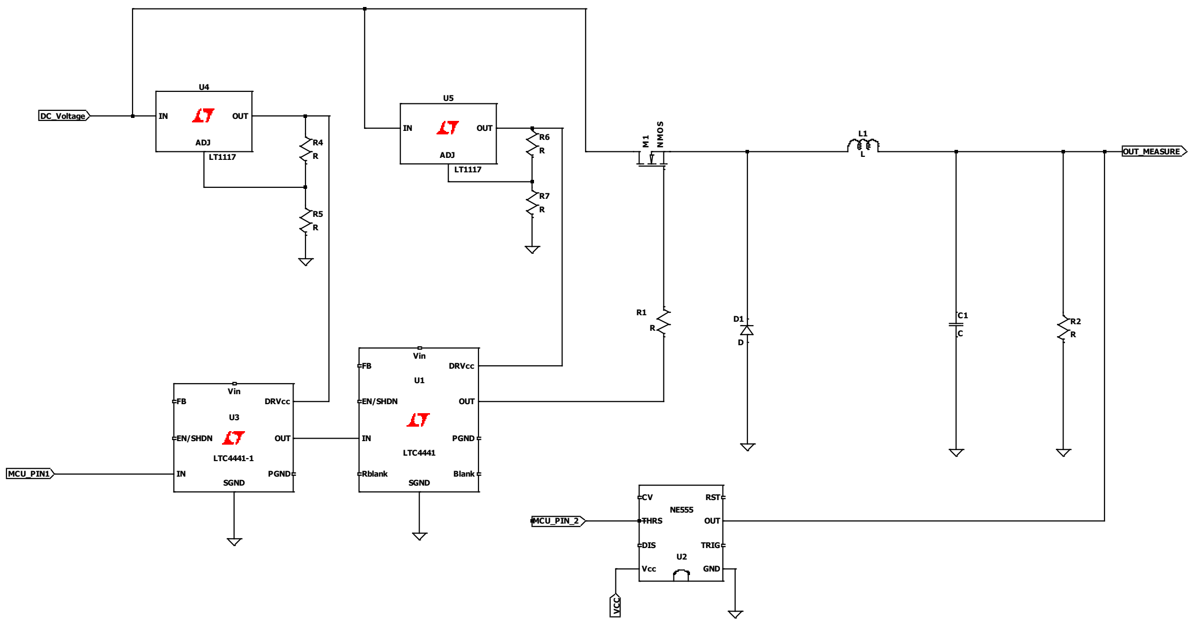


Figure 3: Circuit diagram of microcontroller

UML Diagram:

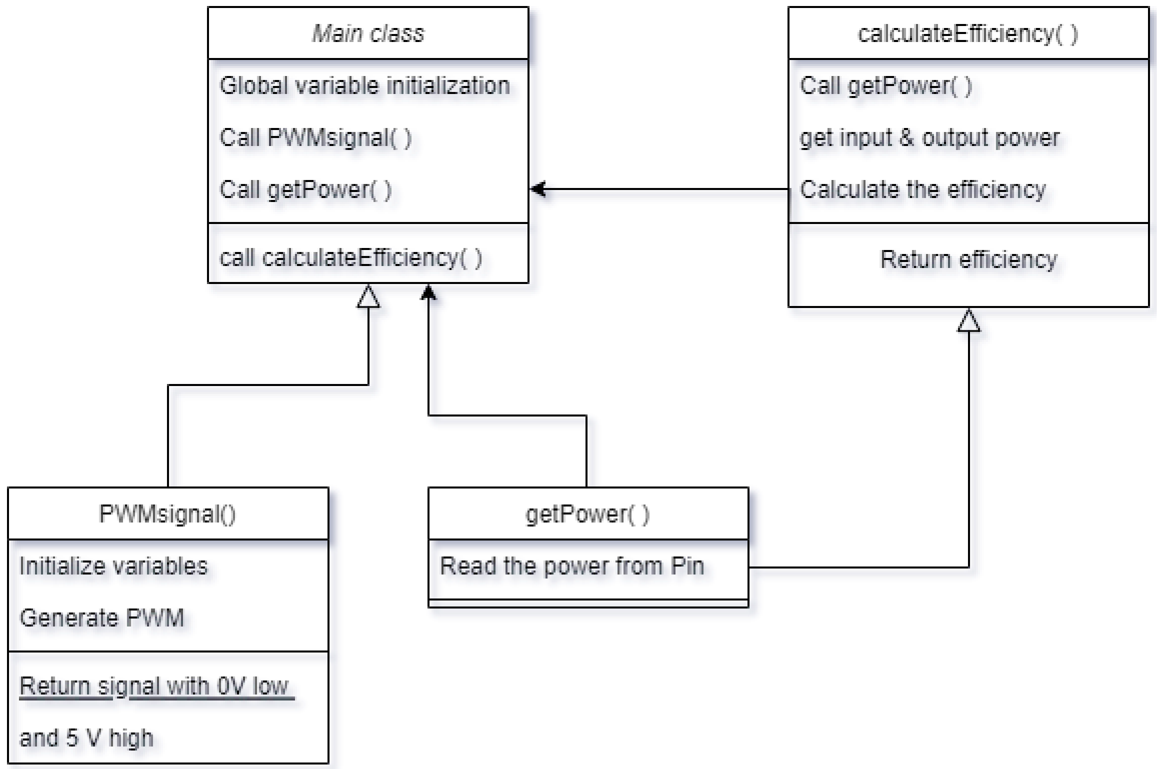


Figure 4:UML Diagram of Software Program

3. Overall Design

Implementation Strategy:

The implementation strategy outlines the step-by-step approach to realizing the SMPS design, encompassing various subsystems and components. The goal is to efficiently convert the 220Vrms AC mains voltage into a regulated 5V DC output while ensuring the seamless transition between modes and optimal performance.

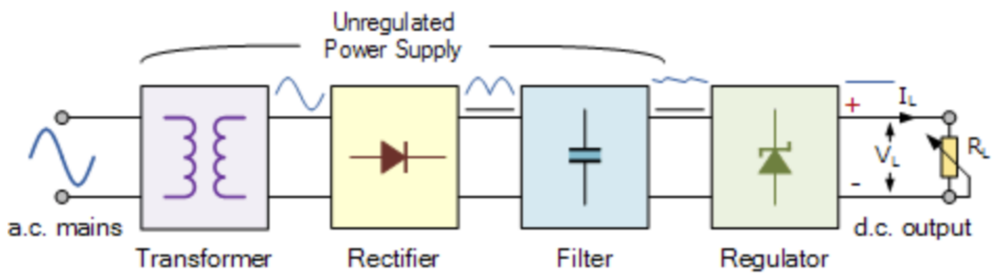


Figure 5 SMPS Functional Diagram

A fully functional circuit diagram depicting the integration of all subsystems is provided below. Each subsystem's performance will be thoroughly analysed to ensure the efficient conversion of 220Vrms AC to a regulated 5V DC output. This comprehensive analysis will confirm that the SMPS meets the project's objectives, including voltage regulation, efficiency, and mode switching capability.

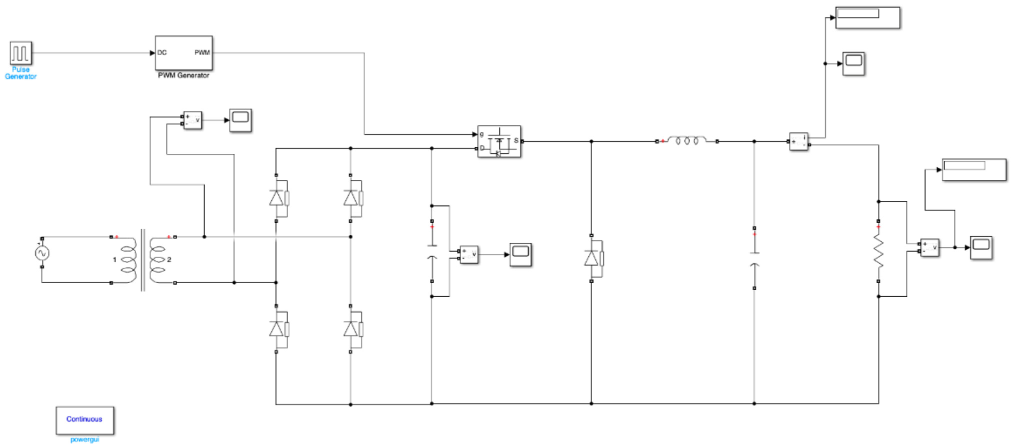


Figure 6 Proposed SMPS circuit design.

Acceptance Test Procedure

The acceptance test procedure will ensure that the design meets its intended performance. The procedure involves defining figures of merit, designing experiments to evaluate these metrics, and establishing acceptable performance standards.

<u>Figures of merit:</u>

ATP ID	ATP name	Figures of merit

ATP001	Voltage Regulation	This is about making sure the output voltage stays steady even when things change. We want to know if the SMPS can keep the voltage where we want it, no matter what's happening.
ATP002	Efficiency	This tells us how good the SMPS is at turning the input power into useful output power. It's like checking if we're not wasting too much energy during the conversion process.
ATP003	Transient Response	This checks how quickly the SMPS can handle sudden changes in power demand. We want to see if the output voltage behaves well even when there's a sudden shift in the load.
ATP004	Switching Frequency Stability	We're looking at how consistent the switching of the SMPS is. It's like making sure the rhythm of the system stays steady.

<u>Experiment Design:</u>

ATP ID	**ATP name**	**Test**
ATP001-T1	Voltage Regulation	We'll suddenly change the load to see if the SMPS can keep the output voltage steady. We'll watch the output voltage closely and check if it stays within a certain range of the desired voltage.
ATP002-T2	Efficiency	We'll change the load (the power being drawn) from low to high and see how the SMPS handles it. We'll calculate the efficiency for different load levels and

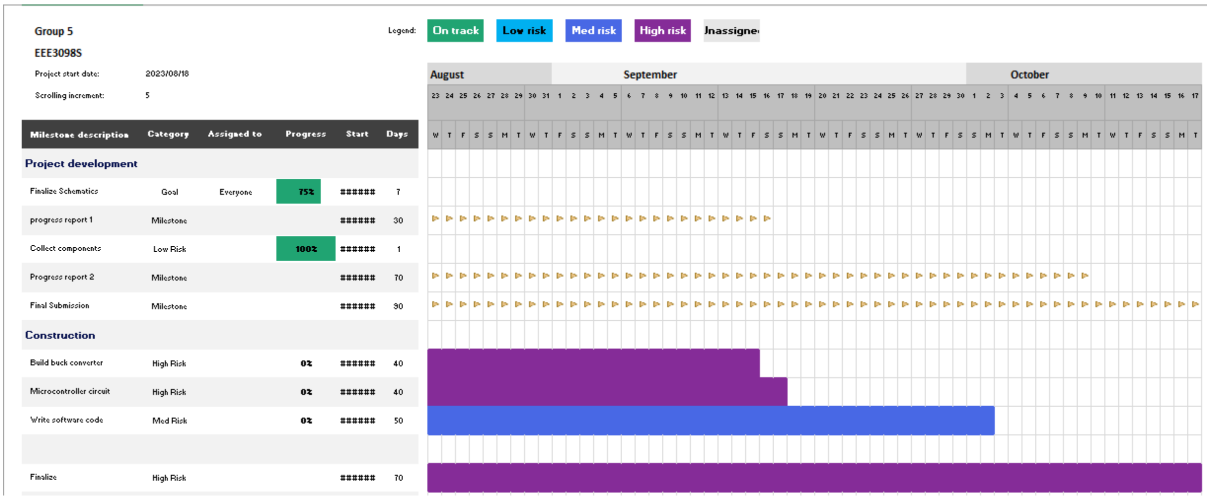
		see if it's at least 80% efficient, as we planned.
ATP003-T3	Transient Response	We'll quickly change the load and see how the output voltage reacts. We want to make sure the voltage doesn't swing around too much during these quick changes.
ATP004-T4	Switching Frequency Stability	We'll change the input voltage and the load and see how the switching frequency behaves. We'll see if the switching speed stays pretty consistent no matter what we do.

Acceptable Performance Definitions:

ATP ID	ATP name	Acceptable Performance
ATP001-A1	Voltage Regulation	We consider it good if the output voltage stays within a small range (±5%) of what we want, no matter how much power we need.
ATP002-A2	Efficiency	We're happy if the efficiency is 80% or more across different power levels.
ATP003-A3	Transient Response	The response is great if the voltage doesn't jump around more than a little bit (±2%) during load changes.
ATP004-A4	Switching Frequency Stability	We're good if the switching speed doesn't change much (±2%) from the normal rate, even when we change things around.

By running these tests and comparing the results to what we think is good performance, we'll be able to say whether our SMPS design works the way we planned.

Development Timeline



Individual Contributions

<u>Ruviel Perumal (PRMRUV001):</u>

- Introduction
- Requirement Analysis
- Development Timeline
- AC to DC research
- Compiled Documentation

<u>Sivuyile Nose (NSXSIV001)</u>

- Acceptance Test Procedure
- DC to DC submodule
- Compiled documentation
- Bibliography

<u>Steve Muhilane (MHLSTE012)</u>

- Microcontroller submodule
- Acceptance Test Procedure
- Compiled documentation.
- UML Diagram.

Bibliography

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