

APPLICATION OF MAGNETIC AMPLIFIER IN POWER ELECTRONICS

A Project Report

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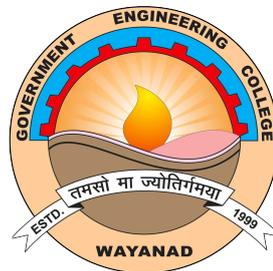
in partial fulfillment of the requirements for the award of the Degree

of

Bachelor of Technology

in

Electrical and Electronics Engineering



Department of Electrical and Electronics Engineering

Government Engineering College Wayanad

DEPT. OF ELECTRICAL & ELECTRONICS ENGINEERING
GOVERNMENT ENGINEERING COLLEGE WAYANAD
2023 - 2024



CERTIFICATE

This is to certify that the Project report entitled “*Application Of Magnetic Amplifier In Power Electronics*”. submitted by **ANET ANTO, ASWANTH M C, ERIN ROSE ANTONY, SWAPNIL P** to the APJ Abdul Kalam Technological University in partial fulfillment of the requirements of the award of the Degree of Bachelor of Technology in Electrical and Electronics Engineering is a bonafide record of the project work carried out by him under my guidance and supervision. This report in any form has not been submitted to any other university or institute for any purpose.

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DECLARATION

We hereby declare that the project report **APPLICATION OF MAGNETIC AMPLIFIER IN POWER ELECTRONICS**, submitted for partial fulfillment of the requirements for the award of degree of Bachelor of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by us under supervision of Prof. BINOY K.P

This submission represents our ideas in our own words and where ideas or words of others have been included, we have adequately and accurately cited and referenced the original sources.

We also declare that we have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in our submission. We understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

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ABSTRACT

Magnetic amplifiers, originally known as saturable core reactors, have revolutionized electrical engineering. With an iron core wound with multiple coils. By varying the control winding current we can vary the inductance. A variable inductor adjusts its inductance based on control current, which regulates the magnetic core's reluctance. This core's permeability changes via control current, introducing a DC magnetic flux. Typically used from linear to saturated states, its inductance varies inversely with the main winding current. They enable dynamic voltage regulation, crucial in various applications. Their inherent features, such as noiseless operation, high efficiency, and remote control capability, make them invaluable.

In power electronics circuits, substituting traditional inductors with magnetic amplifiers allows dynamic adjustment of inductance in response to varying loads, enhancing control and efficiency. By varying inductance, they transition between continuous and discontinuous modes, adapting the circuit's operation. Adjusting inductance ensures stable performance for heavy loads, maintaining continuous mode operation. Conversely, for light loads, transitioning to discontinuous mode by adjusting inductance reduces energy loss and improves efficiency. This dynamic variation of inductance optimizes the converter's performance across load conditions.

ACKNOWLEDGEMENT

Success and happiness are directly related to the achievement of the predetermined goals. The success of this project work is due to the varied contributions of several distinguished personalities. We take this wonderful opportunity to thank every one of them. It is our privilege to extend my sincere gratitude to all those who helped me in the fruition of the Project entitled “*Application Of Magnetic Amplifier In Power Electronics*”.

First of all, we thank God Almighty for being the guide and light throughout the seminar and helping us to complete it within the stipulated time.

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We also express our heartfelt gratitude to our internal guide **Prof. Binoy K P** for timely suggestions and encouragement given for the successful Project phase 2 completion. We would always oblige the helping hands of all other staff members of the department who directly or indirectly contributed to this venture.

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Chapter 1

INTRODUCTION

In the United States, magnetic amplifiers were first created in 1885. They were referred to as saturable reactors back then, and their main applications were in theatrical lighting and electrical gear. It is necessary to have a sufficient understanding of magnetism, electromagnetism, and magnetic circuits in order to comprehend the working principles of magnetic amplifiers. An electromagnetic device known as a magnetic amplifier uses the core saturation concept and core nonlinear feature of a transformer to enhance electrical signals. It is made out of an iron core that has been wrapped in two or more coils. In its inductance varies as a function of control current[2]

Magnetic amplifiers were used for controlling and regulating power in electrical systems. They could adjust the level of AC power delivered to a load by varying the saturation level of the magnetic core. They were employed in voltage regulation circuits to maintain a stable output voltage. By adjusting the magnetic characteristics of the core, they could control the output voltage in response to changes in the input. In radio frequency (RF) circuits, magnetic amplifiers were used in AGC circuits to automatically adjust the gain of the amplifier based on the strength of the incoming signal. This helped maintain a consistent output level despite variations in the input signal. Also used in motor control applications to regulate the speed and torque of electric motors. By adjusting the magnetic properties of the core, they could control the power delivered to the motor. Magnetic amplifiers were used for signal amplification in various systems. [4]-[8] While they were not as widely used as other amplification technologies, they found applications in situations where their unique characteristics were advantageous. Magnetic

amplifiers were employed in the stabilization of power systems, helping to mitigate voltage fluctuations and ensure the reliability of the electrical grid.

Increasing or decreasing the output current in response to changes in the input is a magnetic amplifier's main goal. It offers consistent control throughout a large range without cutting off the main circuit's power. By adjusting the core's saturation, they provide noiseless control and can be remotely operated manually or automatically. Magnetic amplifiers are used to switch circuit connections or to turn on or off the current flowing to a load. Power transfer precision is increased by the precise and consistent currents provided by a magnetic amplifier. In general, step-less control, long life, high power gain, noiseless operation, high efficiency, remote control capability, safety, precision, dependability, and maintenance benefits are the goals of magnetic amplifiers[3].

Small magnetic amplifiers were used for radio tuning indicators, control of small motor and cooling fan speed, and control of battery chargers. Magnetic amplifiers were used extensively as the switching element in early switched-mode (SMPS) power supplies, as well as in lighting control. Here we deal with the application of this magnetic amplifier in a power electronics circuit. Instead of an inductor in a buck converter, we use a magnetic amplifier to vary the inductance value according to the load that is applied to the circuit

Chapter 2

PROBLEM STATEMENT

- Discontinuing a mode under heavy load may lead to increased system strain, potential performance degradation, and user experience issues. It may also result in slower response times, increased latency, and a higher risk of service disruptions, negatively impacting overall reliability.
- Obtaining continuing mode under heavy load can achieve advantages such as maintaining system stability, ensuring uninterrupted service, and avoiding potential disruptions. It allows the system to prevent bottlenecks and minimize the impact on user experience.
- By using a magnetic amplifier as a variable inductor we can switch this discontinued mode to a continued mode.

2.1 Objectives

Design and implement a magnetic amplifier which varies the inductance as a function of control current. It provides uniform control over a wide range without interrupting power in the main circuit and offers noiseless control by altering the saturation of the core. It also provides accurate and predictable currents, improving the accuracy of power transfer. Application of this magnetic amplifier as variable inductor is done DC-DC buck converter.

Chapter 3

METHODOLOGY

Methodology refers to the systematic, theoretical analysis of the methods applied to a field of study. This methodological section consists of the basic schematic diagram, design of the buck converter and magnetic amplifier, simulation and cost estimation.

3.1 System Description

This is the fundamental buck converter reference circuit using a magnetic amplifier in place of an inductor figure 3.1. A magnetic amplifier is an electromagnetic device that uses the core linear property and the transformer's core saturation principle. It is made by wrapping two coils around a ferrite core.

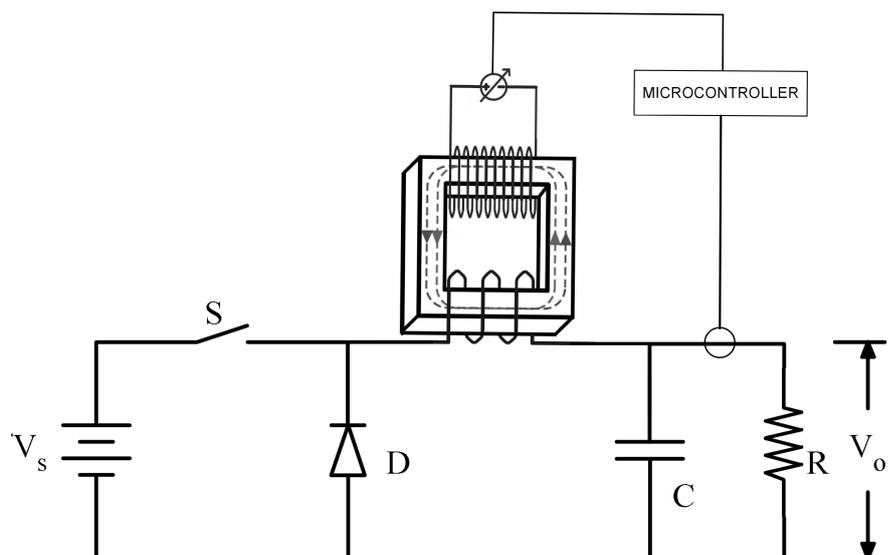


Figure 3.1: Basic schematic daigram

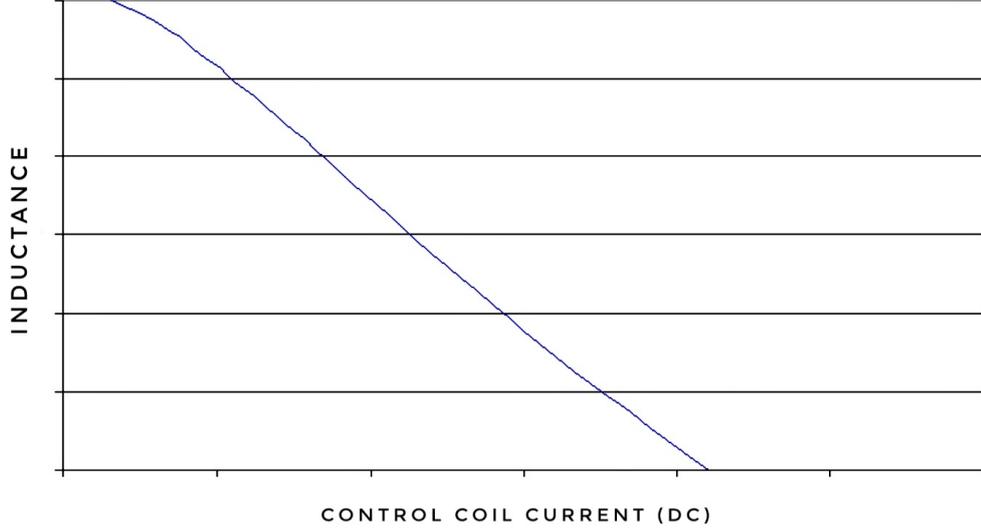


Figure 3.2: Inductance VS Control coil current

The primary winding and the control winding are separated. A DC source is used to change the current flowing through the control winding. With the aid of this feedback loop and micro controller, the DC supply to control winding will be adjusted in accordance with variations in load. The system tends to operate in discontinuous conduction mode under heavy loads; however, we can maintain continuous conduction mode under heavy loads by adjusting the inductance value. Suitable for light load as well.

$$L_{main} = \frac{V_{Dclink} - V_{load}(D_s T_s)}{\Delta i_{main}} \quad (3.1)$$

By varying the value of inductance, the mode of operation can vary. It may be either in continuous or discontinuous mode of operation. As per the figure 3.2, the load decreases as the control current increases.[1]

3.2 Design

Designing a system helps in clearly defining the objectives and goals that the system is supposed to achieve. It sets the direction for development and implementation efforts. Efficient resource utilization and cost-effectiveness are critical considerations.

3.2.1 Buck Converter

Design a buck converter with an input voltage of 20 V and an output voltage of 10 V operating at a switching frequency F_{sw} of 10 kHz. A varying load is connected to the buck converter.

- 1 Select the gate circuit components as discussed in the previous lab.
- 2 The duty cycle of the buck converter is 0.5.
- 3 The peak-to-peak ripple current in the inductor for the given condition is 0.24 A. The average current through the inductor is 0.6 .
- 4 For an output capacitor of 22 μ F, the peak to peak ripple voltage across the capacitor will be 0.136 V.
- 5 To keep the converter at CCM, a minimum inductance (critical inductance) will be there. It is given by,

$$L_C = \frac{R(1 - D)}{2F} \quad (1)$$

Load	Current	Inductance(CCM)
5 Ω	2A	0.14 mH
10 Ω	1.03A	0.269 mH
15 Ω	0.62A	0.45 mH

Table 3.1: Variation of load in buck converter

Buck converter is designed as per the equations shown below

$$V_o = DV_s = 0.5 \times 20 = 10V \quad (3.2)$$

$$I_L = \frac{V_o}{R} = \frac{10}{15} = 0.66A \quad (3.3)$$

$$\Delta I_L = \frac{D(1 - D)V_S}{fL} = 1.11 \quad (3.4)$$

$$I_{Lmax} = I_L + \frac{\Delta I_L}{2} = 1.175A \quad (3.5)$$

$$I_{Lmin} = I_L - \frac{\Delta I_L}{2} = 0.065A \quad (3.6)$$

3.2.2 Magnetic Amplifier

The relative permeability and the effective magnetic path length of the core is denoted by μ_r , and l_e , respectively. The core area is denoted by A_e , and the window area is by A_w . The total turns must be accommodated in the window of the core. For a wire with cross section of a_w , the total number of conductors that can be accommodated in the window is given by,

$$N = \frac{A_w k_w}{a_w} \quad (3.7)$$

where k_w is the window space factor. The wire cross section is decided by the maximum current per unit cross section allowed. When this limit is exceeded, the wire will melt or deteriorate. The safe current density for the conducting material is denoted by JA/m^2 . The magnetic core material can only carry a certain maximum flux density. When this limit is exceeded, the material saturates and the relative permeability μ_r drops substantially. This maximum allowable flux density for the magnetic material is denoted by $B_m T/m^2$. An air-gap of length l_g , may be needed to carry the rated current without saturating the magnetic core. In order to design an inductor of L Henry, capable of carrying an RMS current of I_rms and peak current of I_m , the number of turns required is

$$N = \frac{LI_m}{B_M A_e} \quad (3.8)$$

The air gap required is given by,

$$l_g = \frac{\mu_o N^2 A_e}{L}. \quad (3.9)$$

These calculations based on the assumption that, there is no fringing in the air gap ($(I_g) \gg \sqrt{(A_e)}$) and the reluctance of air gap is much higher than the core ($\frac{l_e}{\mu_r} \ll (I_g)$)

The Buck converter have load range of 0.6A to 2A. For implementing the operation at continuous conduction mode, the inductor has to be designed at range of 0.1mH to 0.5mH

1. The inductor needs to carry a maximum DC current of 2 A.

2. The core is ferrite core E 42/15.
3. The maximum flux density in the core within 0.45 T.
4. The current density J in wire should be less than 3.5 A/mm².
5. Maximum window factor k_w should be limited 0.3.
6. The μ_r for the ferrite core can be taken to be 1500.
7. The number of turns N is given by equation (3.7) On substitution, N=12.
8. The air-gap l_g is given by equation (3.8) On substitution, $l_g = 0.66$ mm.
9. The window factor k_w is given by

$$k_w = \frac{N a_w}{A_w} \quad (3.10)$$

10. For E 42/15 core $A_w = 276 \text{ mm}^2$ and for SWG 23, $a_w = 0.2919/\text{mm}^2$. On substitution, $K_w = 0.04$, which is less than maximum specified.
11. The current density is given by ,

$$J = \frac{I}{a_w} \quad (3.11)$$

On substitution, $J=3.4 \text{ A/mm}^2$.

12. The number of turns in the control winding is 22(obtained from the simulation)

3.3 Microcontroller

The Arduino Uno's compatibility with a wide range of sensors, utilizing its analog and digital pins, makes it versatile for interfacing with temperature, humidity, light, and motion sensors. This capability enables applications like environmental monitoring and home automation. When integrated into power electronics systems like buck converters, the Uno's sensor compatibility allows real-time monitoring and dynamic adjustment of parameters, enhancing efficiency. With Arduino IDE support and a large developer community, incorporating sensors into Uno-based



Figure 3.3: Arduino-Uno

projects, including buck converters, is straightforward, appealing to both beginners and experienced users.

3.4 Current Sensor

The ACS712 current sensor module measures current by detecting the magnetic field generated by the current passing through a nearby conductor using the Hall Effect principle. It provides analog voltage output proportional to the current, with sensitivity specified in millivolts per ampere. The sensor can measure both AC and DC currents accurately and comes in different variants with varying current measurement ranges.



Figure 3.4: ACS712

3.5 Simulation

Simulations are often used to analyse the system and its behaviour. It helps in optimizing the system by testing different scenarios. Here, it is done in the FEMM and LT spice software.

3.5.1 Using FEMM Software

The magnetic amplifier is simulated in FEMM software using the required components. Core with and without control winding is simulated.

Magnetic core without control winding, in this the flux is almost uniformly distributed throughout the core. Magnetic amplifier with control winding, the flux is concentrated in one core. This non-uniform flux distribution will make the core more suitable for a magnetic amplifier as a variable inductor.

3.5.2 Using LT-Spice Software

The buck converter is simulated in LT spice software and the variation in the inductance from discontinuous to continuous conduction mode is examined.

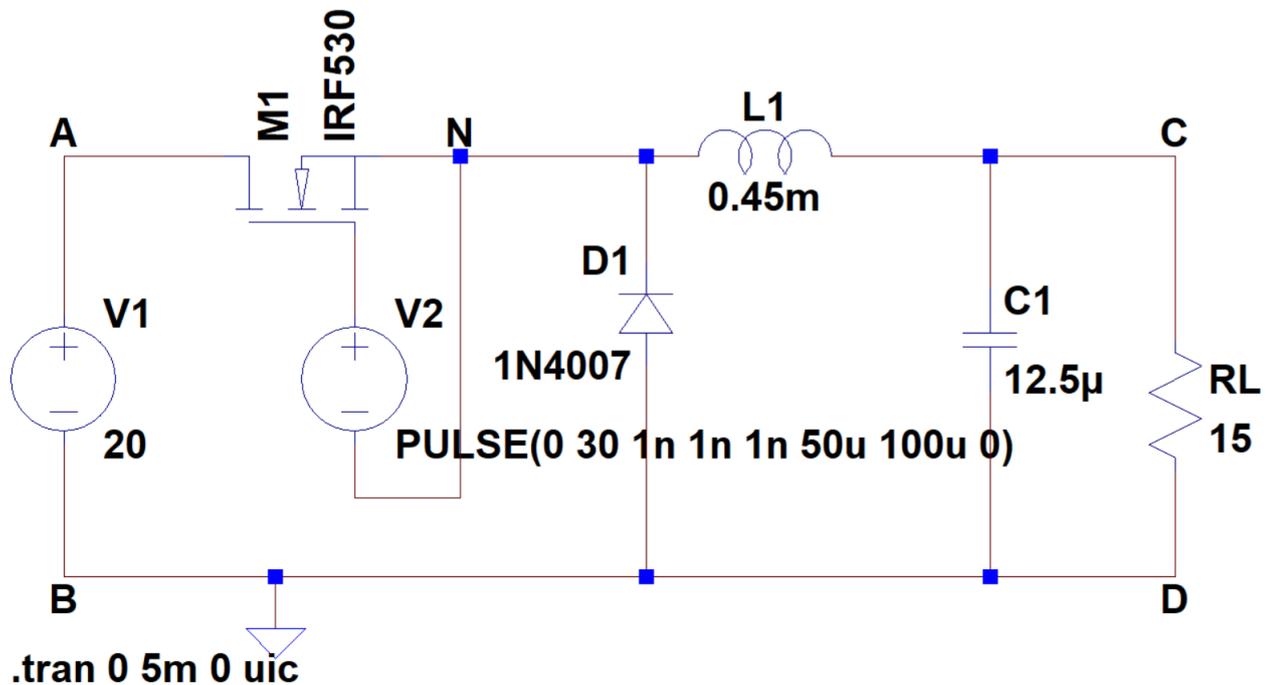


Figure 3.5: Buck Converter

3.5.3 Using MATLAB Software

Using MATLAB software, a simulation of a buck converter was conducted. The buck converter and feedback are designed using an m-file, a simple text file where commands can be placed. This is done to vary the inductance. The results for this setup are given in Chapter 4.1.3.

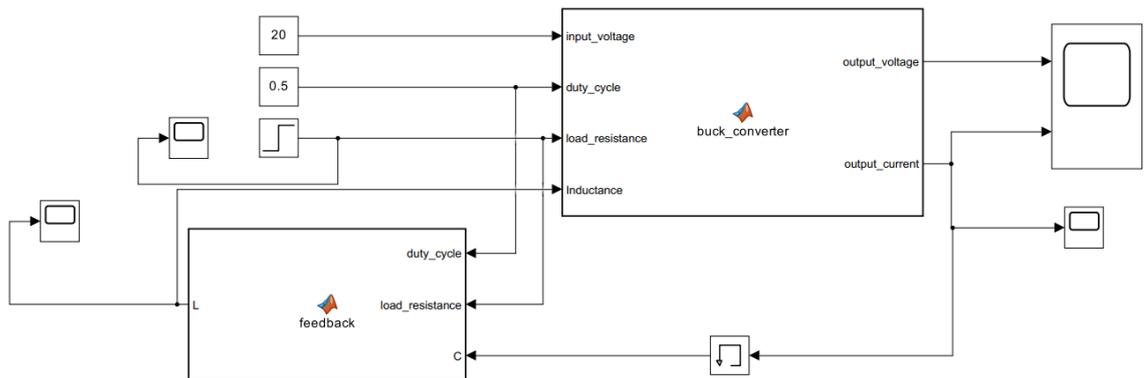


Figure 3.6: Buck Converter with feedback

Chapter 4

RESULTS

4.1 Simulation Results

4.1.1 Using FEMM Software

Simulated a magnetic amplifier in FEMM (Finite Element Method Magnetics) software involves modeling the core and windings to analyze its magnetic properties and performance.

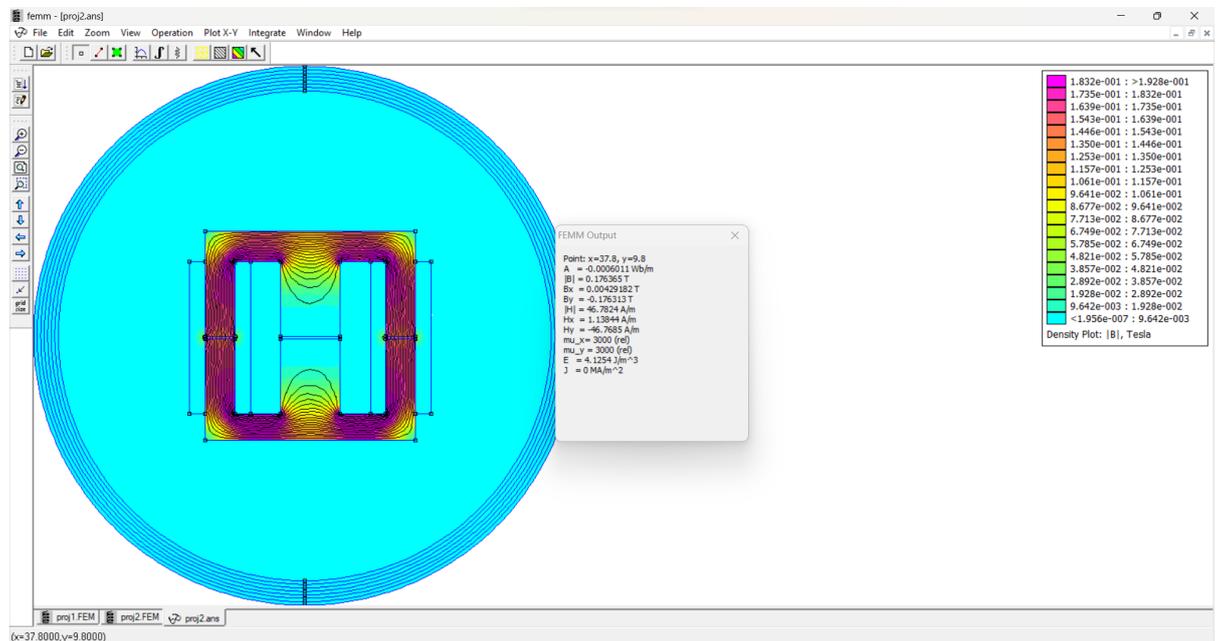


Figure 4.1: Core without control winding

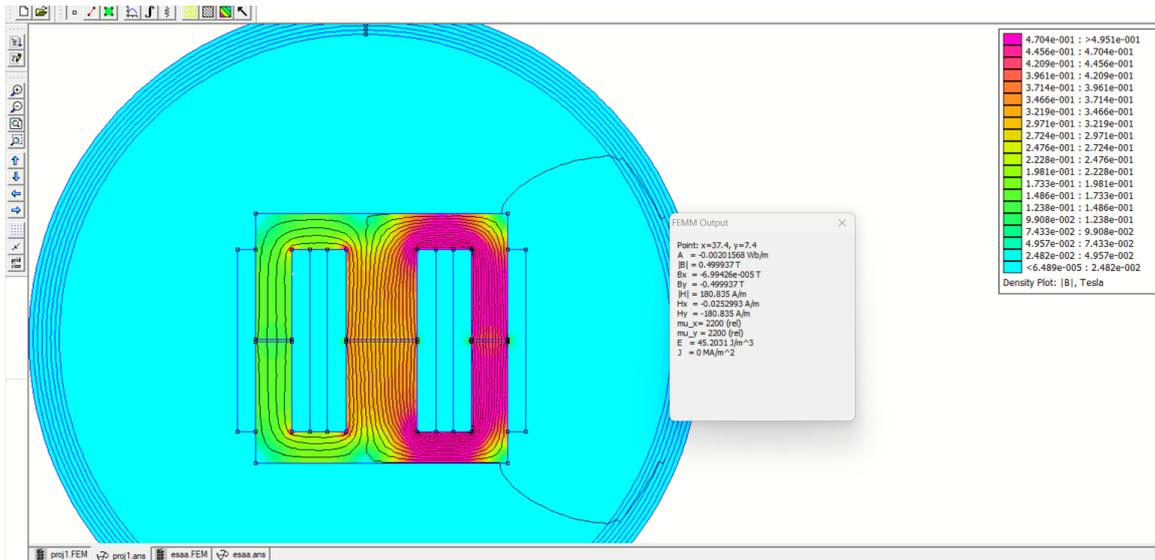


Figure 4.2: Core with control winding

4.1.2 Using LTspice Software

For different load values, the inductance and current are measured. In heavy load the converter will move to discontinuous mode, by changing the value of inductance the converter can remain in continuous mode and vice versa in light load. This variation in inductance is done here with the help of control winding. By varying the DC source in the control winding, the inductance value also varies.

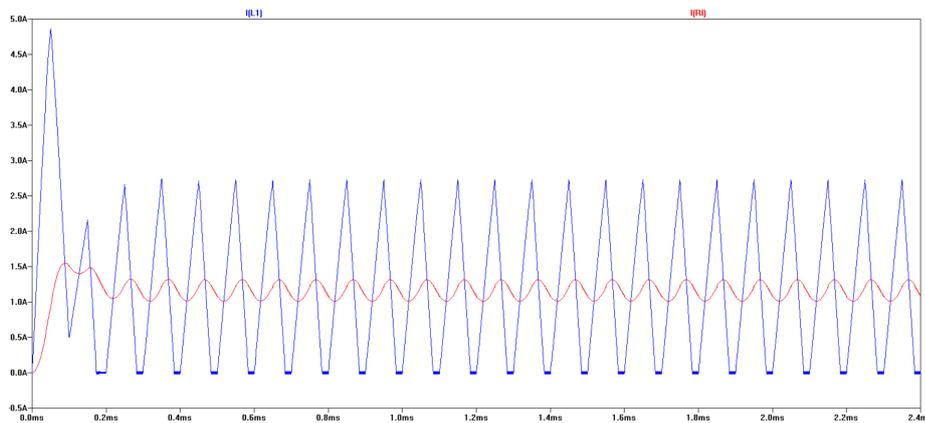


Figure 4.3: Discontinuous Conduction Mode

In a system, the conduction mode varies with load. For better efficiency, the system must be remain at CCM in heavy load and DCM in light load.

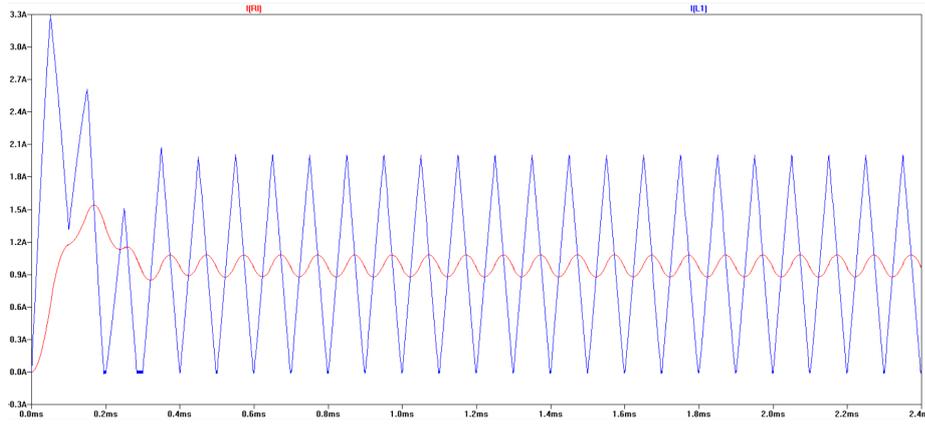


Figure 4.4: Continuous Conduction Mode

Current(A)	Inductance(mH)	Mode of operation
0.4	0.8	Discontinuous
0.35	2	Continuous

Table 4.1: For a load of 25Ω (from LT Spice)

4.1.3 Using MATLAB Software

Different load conditions were tested to measure the inductance and current in the buck converter. As the load increases, the converter shifts to discontinuous mode, but adjusting the inductance allows it to maintain continuous mode, achieved through modulation of the inductance via a control winding. This modulation is achieved by varying the DC source applied to the control winding.

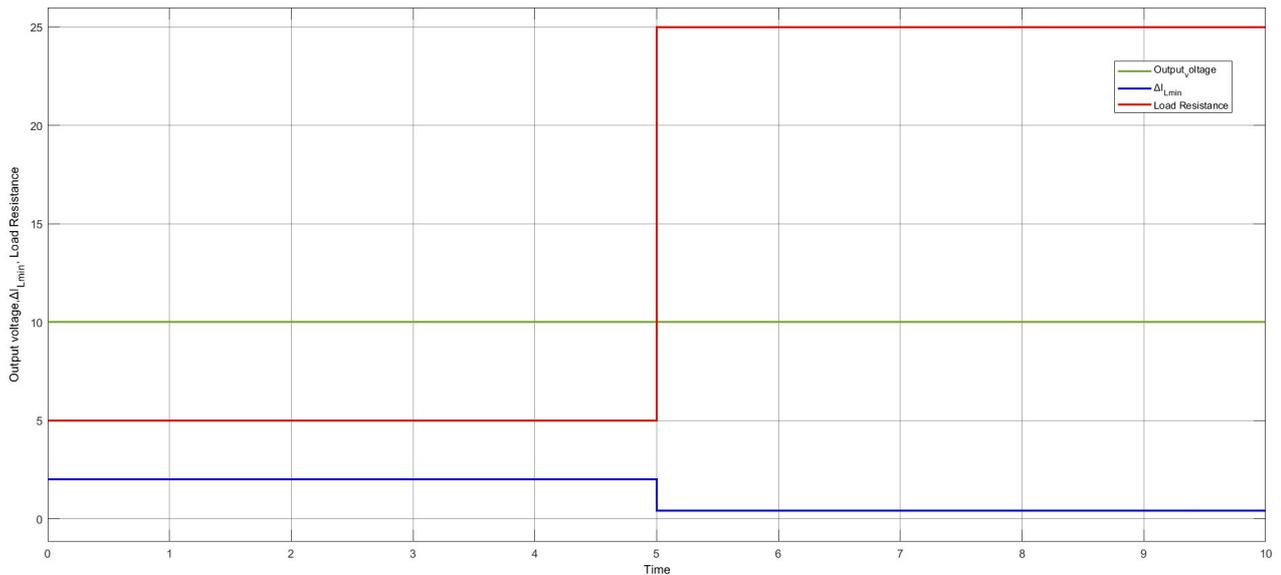


Figure 4.5: Graph depicting the output voltage, ΔI_{Lmin} , and load resistance VS time

4.2 Case Study

Conducted sample hardware of magnetic amplifier with simplified values and available components. The output waveform is given in Figure 4.3.

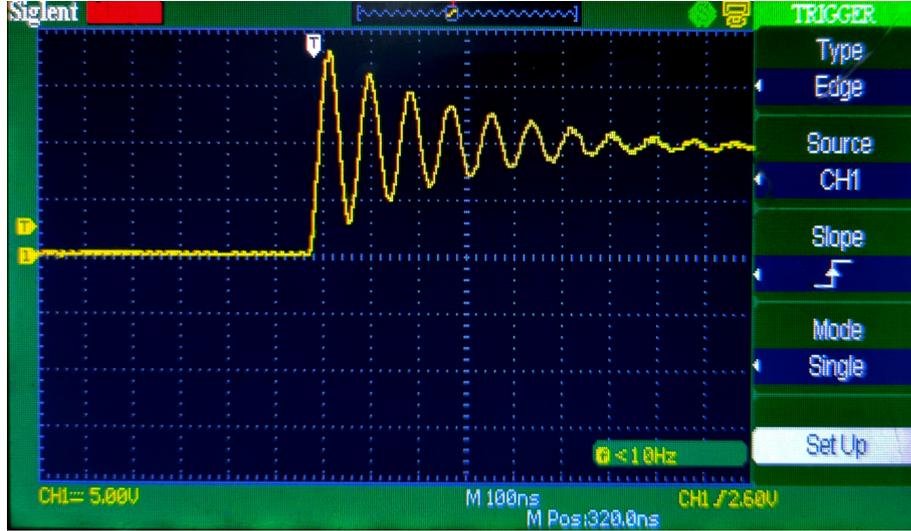


Figure 4.6: Time response of sample prototype(N=12)

The output consists of comparatively less capacitance in this RL circuit. Hence the number of turns in the winding is increased. As a result, the corresponding response of the RL circuit is obtained.

From the graph shown in Figure 4.5 the time constant value obtained is mentioned in Table 4.1. The time constant is given by;

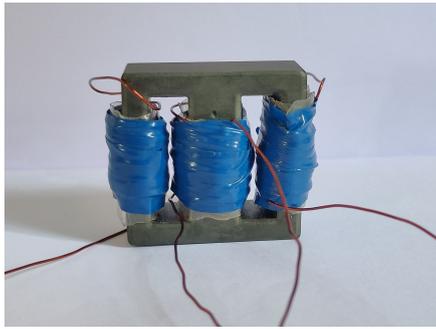
$$\tau = \frac{L}{R} \quad (4.1)$$

For $R = 5\Omega$

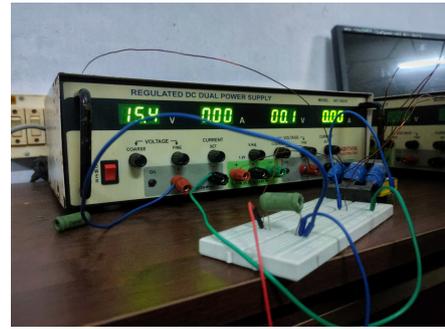
Contol winding current	Time constant	Inductance
0.0 A	71 μs	0.35 mH
0.7 A	54 μs	0.27 mH
1.5 A	47 μs	0.23 mH

Table 4.2: Test result of sample hardware

Figure 4.4(a) shows the sample prototype of the magnetic amplifier Figure 4.4(b) is the experimental setup Figure 4.5 consists of three time responses ob-

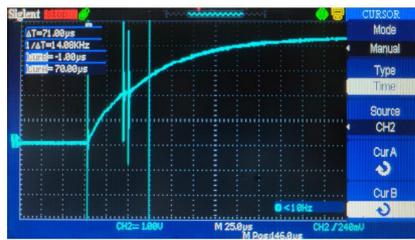


(a)

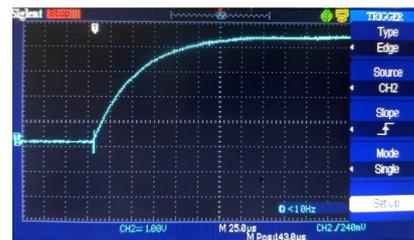


(b)

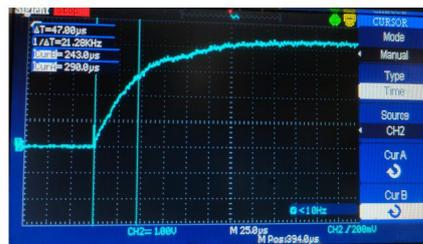
Figure 4.7: Testing setup of sample hardware.



(a) $L=0.35\text{mH}$



(b) $L=0.27\text{mH}$



(c) $L=0.23\text{mH}$

Figure 4.8: Time response of sample hardware($N=36$)

tained from the sample prototype 63.32 per cent of the maximum amplitude value is considerable from the graph. Inductance value is measured by using the equation 4.1. Inductance value decreases with an increase in control winding current

Chapter 5

EXPERIMENTAL SETUP

The hardware setup includes crucial components such as a magnetic amplifier, buck converter with gate drive circuit, rectifier, and step down transformer. A magnetic amplifier consists of a ferrite core with two coils wound on it. The controlled winding (main winding) is connected across the buck converter, and the control winding has a DC supply. After conducting various case studies and practical winding sessions, we have decided to implement 70 turns in the main winding and 60 turns in the control winding. The main winding has been divided into two equal sections and connected to separate legs of core. The winding is done using copper wire, and the core used is an E-core. A buck converter consists of several key components.

5.0.1 MOSFET IRF540N



Figure 5.1: IRF540N

The switch, such as the IRF540N (MOSFET or BJT), shown in figure 5.1 rapidly switches the current on and off, controlling the flow of energy from the

input to the output. The IRF540N is a high-voltage N-channel MOSFET, prized for its low on-resistance and suitability for medium to high-power applications like power supplies and motor control.

Its drain-source voltage (VDS) is 100V, and its continuous drain current (ID) is 33A.

5.0.2 MUR480



Figure 5.2: MUR480

The diode used is the MUR480, shown in figure 5.2 known for its fast recovery time and low forward voltage drop, making it suitable for use in power supplies, voltage regulators, and other circuits where efficient switching and minimal losses are crucial. It is commonly employed in higher frequency switching applications.

5.0.3 TLP250 Optocoupler



Figure 5.3: TLP250 Optocoupler

The TLP250 shown in figure 5.3 features a Gallium Aluminum Arsenide infrared LED coupled with a photo-detector, ensuring high-speed signal transmission with minimal propagation delay. It offers high noise immunity and reliable

isolation, making it suitable for use in noisy environments and applications requiring galvanic isolation. Additionally, its compact and robust design enhances its versatility and reliability in various industrial and automotive applications.

5.0.4 Operation

The magnetic amplifier's control winding allows precise adjustment of the inductance in the main winding, crucial for toggling the buck converter between continuous and discontinuous modes to handle varying loads. By modulating the current in the control winding, the flux distribution within the magnetic amplifier alters, directly influencing the buck converter's inductance and ensuring stable performance across diverse conditions. While increasing the current in the control winding of the magnetic amplifier, the inductance value in the main winding has been decreasing. This was measured using an LCR meter. Meanwhile, the buck

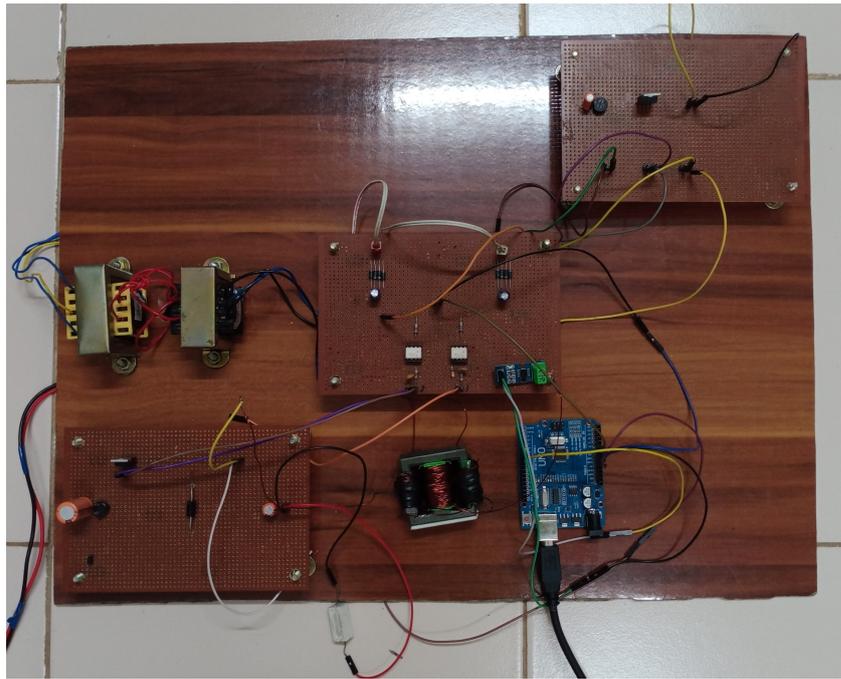


Figure 5.4: Prototype-Hardware

converter's gate drive circuit controls MOSFET switching, providing voltage during switch-on for energy storage in the inductor and maintaining a steady output voltage during switch-off. This coordinated operation guarantees efficient energy transfer and precise voltage regulation, applicable not only in buck converters but also in circuits relying on inductor value regulation.

Chapter 6

CONCLUSION

Developing a Saturable Core Reactor (Magnetic amplifier) based device for power electronics circuits involves setting up an iron core with two or more coils wound around it. The controlled circuit is decoupled from the control circuit. By varying the inductance value according to the variation in load, we can convert the discontinuous mode to continuous mode under heavy loading and vice versa. Achieving continuous mode operation under heavy load offers advantages such as maintaining system stability, ensuring uninterrupted service, and avoiding potential disruptions. The absence of mechanical components enhances reliability and reduces wear and tear. The circuit was simulated in LTspice, FEMM, and MATLAB software as per the requirements, yielding the corresponding waveforms. The hardware setup for the magnetic amplifier in the buck converter has been successfully accomplished. This pivotal step involved meticulous assembly and configuration of the requisite components, aligning with the designated design parameters. With this setup in place, the buck converter circuit now possesses the capability to modulate and regulate magnetic flux within the inductor, thereby ensuring precise control over the output voltage. The overall cost is estimated to be around Rs. 2800.

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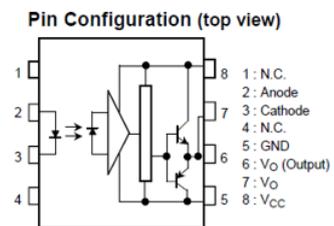
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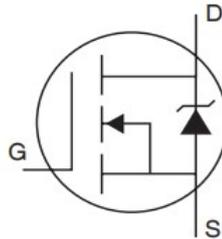
Annexures

A1. TLP250-DATASHEET

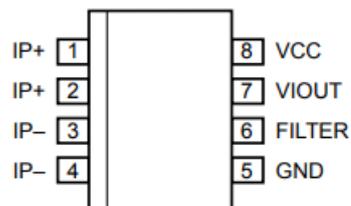
Input Threshold current	5mA
Input Reverse Voltage	5V
Operating frequency	25KHz
Junction Temperature	125°C
Isolation Voltage	2500V
Supply Current	11mA
Supply Voltage	10V - 35V
Output Current	1.5A
Switching time	1.5μS



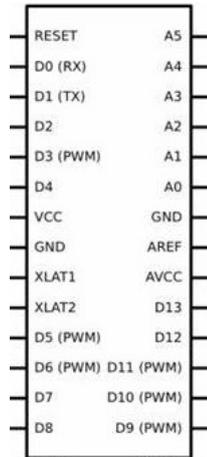
A2. IRF540



A3. ACS712-Pin-Out Diagram



A4. ARDUINO-UNO Pin-Out Diagram



A5. Arduino-Uno code language=C

```
const int analogPin = A0;
const float sensitivity = 0.066;

void setup()
{
  Serial.begin(9600);
  pinMode(9, OUTPUT);
  pinMode(6, OUTPUT);
}

void loop()
{
  int sensorValue = analogRead(analogPin);
  float voltage = sensorValue * (5.0 / 1023.0);
  float current = (voltage - 2.5) / sensitivity;
  Serial.print("Current: ");
  Serial.print(current);
  Serial.println(" A");
  if (current > 4.0)
  {
    digitalWrite(6, HIGH);
  }
  else
  {
    digitalWrite(6, LOW);
  }
  digitalWrite(9, HIGH);
  delayMicroseconds(10);
  digitalWrite(9, LOW);
  delayMicroseconds(100);
  delay(1000);
}
```