MAGNETIC RESET CIRCUIT DESIGN FOR ZERO INDUCED EFFECTS IN LINEAR TRANSFORMER APPLICATIONS

MUHAMMAD HAFIZI BIN AHMED

ELECTRICAL & ELECTRONICS ENGINEERING
UNIVERSITI TEKNOLOGI PETRONAS
JUNE 2010

Magnetic Reset Circuit Design for Zero Induced Effects in Linear Transformer Applications

by

Muhammad Hafizi bin Ahmed

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

June 2010

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Magnetic Reset Circuit Design for Zero Induced Effects in Linear Transformer Application

by

Muhammad Hafizi bin Ahmed

Dissertation submitted to the
Electrical & Electronics Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(ELECTRICAL & ELECTRONICS ENGINEERING)

Approved by,

(Ms. Khairul Nisak binti Md Hassan)
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD HAFIZI BIN AHMED

ABSTRACT

Magnetic reset circuit (MRC) is designed and applied in linear transformer. Since the conventional transformer utilizes the concept of induced voltage current from primary to secondary sides, magnetic reset circuit is designed so that both sides of windings can be used effectively as voltage and current path without inducing any current or voltage to respective windings. The objective in this project is to design and simulate magnetic reset circuit using PSpice Schematics software. There are three common techniques to reset magnetizing energy and this project only deal with one technique only. All circuits in this project used tertiary winding as based circuit added with MRC. In order to improve the capability of MRC, the clipper is added at respective winding to remove unwanted signal, reduced time delay and smoother output response. The expected outcome from this project is switching frequency 1 MHz with a maximum of 5 Ampere forward current are expected to successfully operate in resonant gate driver (RGD).

ACKNOWLEDGEMENTS

First and foremost, I would like to praise to God the Almighty for His guidance. With guidance and blessing bestowed upon me, I managed to overcome all obstacles in completing this project. Here, I would like to use this special opportunity to express my heartfelt gratitude to everyone that has contributed to the success of the project.

My deepest appreciation and gratitude goes to my Final Year Project Supervisor, Ms. Khairul Nisak bt. Md Hasan and my Final Year Project Co-Supervisor, Mr. Nor Zaihar bin Yahaya for their supervision, time, commitment, professionalism, advice and guidance throughout the completion of this final year project.

A special acknowledgement and appreciation goes to:

- Electrical and Electronics Engineering Department for the support.
- Parents for giving support and spirit to complete the project.
- Colleagues for encouragement and help.

Last but not least, special thanks to those who had helped me directly or indirectly in undertaking this project throughout a year. The contributions and insights are highly appreciated.

Thank you to all of you.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Modern power electronic systems are rarely designed without inductors and transformers. By understanding magnetic and magnetic circuits, it is necessary for the successful design of power electronic systems. Transformer consists of two or more windings wrap around common core. If the primary winding is excited by an external source, an induced voltage is created at the secondary winding. Magnetic reset circuit is designed to reset the induced voltage in the transformer. Hence, both sides of windings can be used effectively as a voltage and current path without inducing any current or voltage to respective windings.

1.2 Problem Statement

In DC-DC converter, in spite of having two separate inductors in LC resonant link bridge, linear transformer can be used. However, a conventional transformer utilizes the concept of induced voltage current from primary to secondary sides. Magnetic reset circuit is designed to have both sides of windings can be used effectively as a voltage and current path without inducing any current or voltage to respective windings.

1.3 Objective and Scope of Study

The main objective for this project is to design and simulate a magnetic reset circuit for zero induced effects in linear transformer applications.

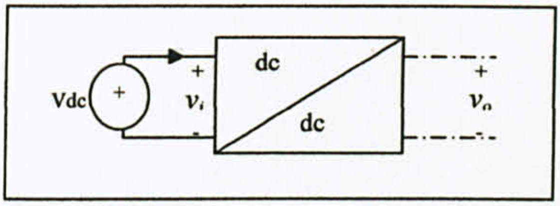
The other objective(s) for this project are:

1. To understand the principles of linear transformer.
2. To understand and identify the magnetic reset circuit in the transformer.
3. To understand the application of magnetic reset in the transformer.
4. To build the magnetic reset circuit and simulate in PSpice software.

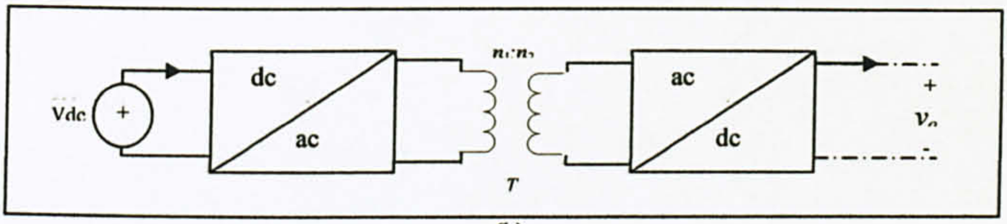
CHAPTER 2
LITERATURE REVIEW

2.1 DC-to-DC Converter

DC to DC converters are used in power electronic circuits to convert an unregulated input dc voltage to a regulated or variable dc output voltage [1].



(a)



(b)

Figure 1: Dc-to-dc conversion. (a) One-stage dc-to-dc conversion. (b) Two-stage dc-to-dc conversion.

Figure 1 shows block diagram of dc-to-dc conversion. The high-frequency resonant-type dc-to-dc converters, used two-stage conversion. Transformers used to provide electrical isolation and step-up/step-down features [1].

In resonant converters, the switching devices are used in such a way that the turn-on or turn-off losses can be reduced or eliminated, depending on the converter operation. Such converters are known as "soft-switching" converters used in the design of high-power density dc power supplies for laptop computers, adapters, notebook computers, and aerospace and communication instrumentation [1].

2.2 Magnetic Circuit

Magnetic circuits consist of inductors and transformers. Most power electronics systems are designed with transformers or inductors. An inductor may act like as parasitic components if not included as discrete components, when operating at high frequencies. Magnetic components are very expensive and hard to design in power system.

Functions of an inductor are:

1) Filter switch waveforms, at both the input and output sides.
2) Form resonant circuits along with capacitor in order to create sinusoidal waveforms for various applications.
3) Limit the rate of change of load currents in switching circuits.
4) Limit transients at power-up of electric systems. [2]

Transformer is a passive device that transforms AC electric energy from one circuit into another through electromagnetic induction. It consists of ferromagnetic core and two or more coils (windings). Changing current creates alternating magnetic field in core. The core multiplies this field and couples the most of the flux through the second winding. This turn induces alternating voltage (e.m.f.) in each of secondary coil according to Faraday's Law.

Functions of a transformer are:

1) Provide step up or step down the voltage.

2) Provide isolation between power systems to reduce various EMI problems and for safety considerations.
3) Provide phase shift in multiphase systems to generate systems with three or more phase.
4) Provide a means to store energy to be utilized at later times, especially in high- frequency applications.
5) Provide a coupling mechanism between the gate or base drive circuits of high-power semiconductor switching devices and the power circuits in various power electronic systems.
6) Provide sensing for voltage and/or current in various controls feedback systems. [2]

Magnetic circuits were used in many practical applications in power electronics. Like discussed earlier, magnetic circuits consist of inductors and transformer. It is desired to get the maximum magnetic field with minimum magnetizing in the coil. Direct proportionality between current and magnetic field density, an attempt to increase the magnetic field intensity will result in an increase in the coil current. [2]

Since flux density, **B** is equal to μ**H,** where μ is magnetic permeability and **H** is flux intensity, flux density can be increased by using material with high permeability compared to air permeability. Ferromagnetic is used since these materials experience strong magnetization in the presence of magnetic field. This property is similar to the property of good conductor material. The flux will flow in a high μ path rather in a low μ of the air.

Magnetic circuit analysis is very useful in the design of inductors, transformers, and other special magnetic devices. For magnetic circuits, we will be dealing with the Maxwell's equations.

$$\oint_c \mathrm{H}\,.dl = -Ni \quad (1)$$

$$\oint_c B.dS = 0 \qquad (2)$$

Equation (1) is Ampere's Law. This law states that the total magnetic field in a closed path of length l must equal the total applied magnetomotive force. In other words, right side of this equation represent as a current source and left side of the equation represent the resultant or induced mmf. Source voltage around a closed loop is equals to the total resultant voltage drop in the same loop.

Equation (2) is Gauss's magnetic law. This law states that the sum of the total magnetic flux, Ø, into a close region must be zero.

2.3 Magnetizing Curve

The behaviour of the ferromagnetic can be observed into magnetizing curve. This curve shows how much flux density, **B** results when increasing the flux intensity, **H**.

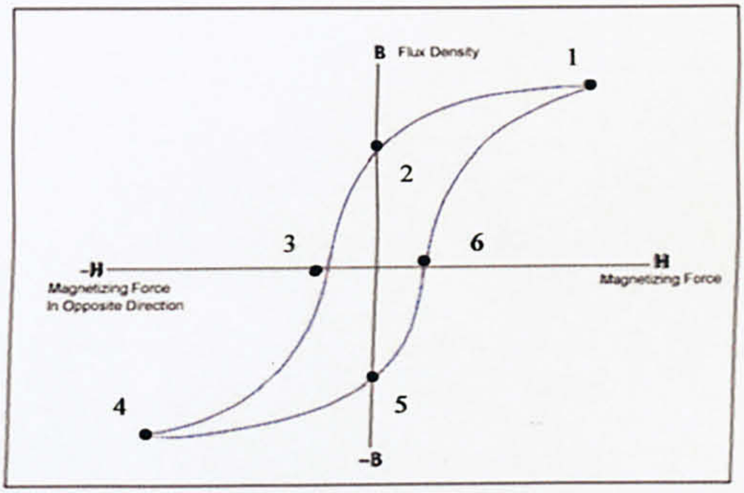


Figure 2: Typical B-H Magnetizing Curve

Figure 2 shows B-H magnetizing curve. The phenomenon illustrated in this figure refers as hysteresis. Loop 123456 is known as the hysteresis loop. First of all let assume magnetic force, H is produced by a sinusoidal varying current and assume material is magnetized and reached its saturation point at 1. When the current start decreasing, the magnetizing current starts following a different path (from 1 to 2). At point 2, magnetic force is zero but magnetic flux remains in the material. This point also known as residual flux or remnant magnetization. Negative magnetic force that forces the flux goes into zero is pointed at 3 (demagnetization). At point 4, the material reaches its negative saturation point. Then the magnetic force starts increasing again and follows different path until its reaches positive saturation again at point 1.

2.4 Transformers

2.4.1 Ideal Transformers

An ideal transformer is assumed that both coil and core losses are negligible and two windings (primary and secondary) are perfectly coupled where they are linked with the same flux [3].

$$\oint E \cdot ds = -\frac{d\phi_B}{dt} \qquad (3)$$

Equation (3) is Faraday's law. Faraday's law states that the induced voltage across a conducting wire is proportional to the rate of change of the flux through the wire with respect to the time.

2.4.2 Non-Ideal Transformers

There are several things need to be considering when dealing with non-ideal transformer [3]. These includes non-perfect coupling between two windings, finite permeability and core losses and copper losses. These factors only need to be considered when dealing with non-ideal transformer.

2.4.2.1 Non-perfect coupling

Since the flux linkage between the two windings is not the same, some flux tends to leaks into surrounding medium. The air permeability is only a few orders of magnitude smaller than the core permeability, resulting in small flux leaving the magnetic path and returning through the air.

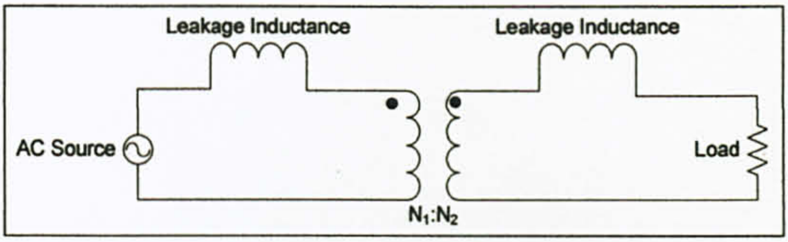


Figure 3: Ideal transformer model with leakage inductances

Figure 3 shows ideal transformer with leakage inductance. The leakage inductance indicated by two inductors which are on primary and secondary side.

2.4.2.2 Finite Permeability

Permeability of the core is not infinite. Primary winding must be excited in order to produce a flux in the secondary winding. The primary current needed to magnetically couple the secondary winding will not be zero when the secondary winding is open-circuited. The current that flows through the magnetizing inductance is called magnetizing current.

2.4.2.3 Core Losses and Copper Losses

There are two types of losses in magnetic structures

1) Copper losses – Exist in the winding coils due to the current conduction.
2) Core losses – Hysteresis losses and eddy current losses.

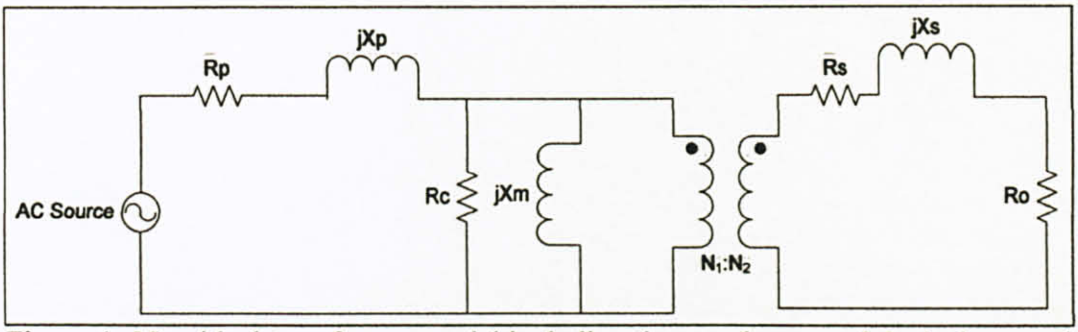


Figure 4: Non-ideal transformer model including the core losses and the leakage and magnetizing inductances.

Figure 4 shows schematic diagram of non-ideal transformer. From the figure, there are many losses such as copper losses and core losses. The voltage drop present across these inductances, resulting in energy loss and, therefore, less efficiency.

Where:

R_p, R_s	: Resistive heating losses
R_o	: Load
jX_p, jX_s	: Leakage Inductance
R_c	: Resistive core losses
jX_m	: Magnetization inductance

2.5 Magnetic Reset Circuit

Magnetic reset circuit or transformer reset circuit is a circuit consists of components such as inductor, capacitor, resistor and diode. Magnetic reset circuit is applied to the respective winding in order to reset the magnetizing energy of transformers.

Furthermore, both windings can be used effectively as a voltage and current path without inducing any current or voltage to the respective windings. There are three (3) conventional techniques in resetting magnetizing energy.

2.6 Techniques in Magnetic Reset Circuit

There are three (3) techniques for resetting magnetizing energy of transformers [4]:

(i) Tertiary winding.
(ii) RCD reset circuit.
(iii) Resonant reset circuit.

2.6.1 *Tertiary winding*

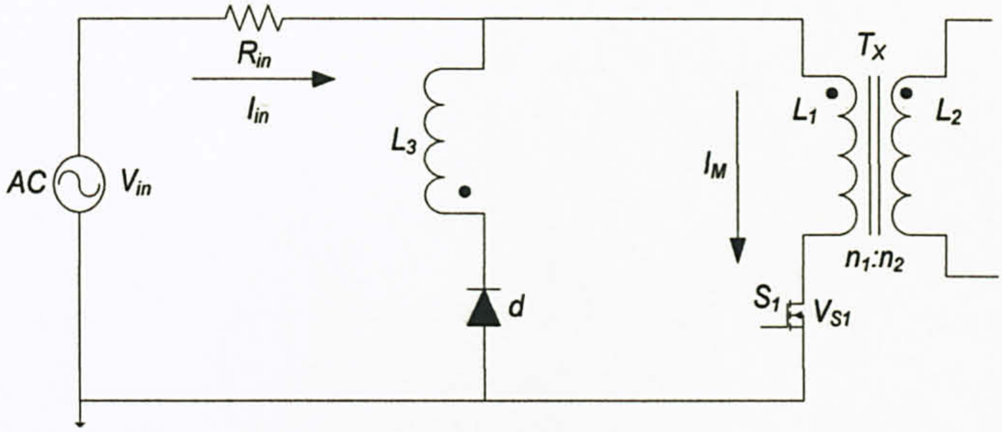
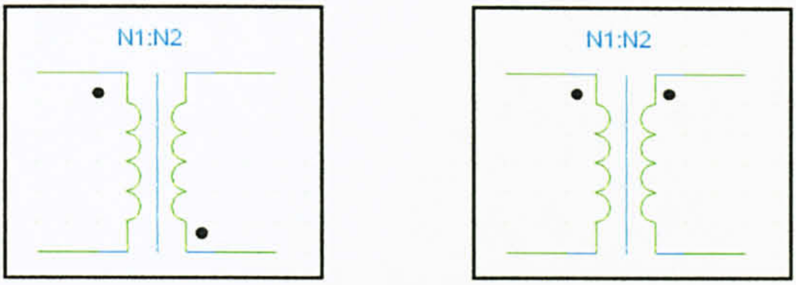


Figure 5: Tertiary winding reset circuit.

Figure 5 shows tertiary winding reset circuit. A diode, *d* is connected in series with tertiary winding, L_3 of transformer.

When switch, V_{S1} is turn ON, transformer charges the magnetizing inductor, L_1 until the switch; V_{S1} is turn OFF and at the same time, the diode, *d* also turns ON. Magnetizing inductor, L_1 discharges through the loop until magnetizing energy is fully discharged.

Magnetizing inductor, L_1 will be conducted again on the next turn ON period. Charging time and discharging time of magnetizing inductor depends on turn-ratio of the primary winding, L_1 to tertiary winding, L_3. If turn ratio is 1:1, the charging time and discharging time of magnetizing inductor will be same.



(a) (b)

Figure 6: Transformer "dot" notation.

Figure 6 shows the transformer "dot" notation. The "dot" notation is used to identify the direction of the windings, either clockwise or counter clockwise. Figure 6(a) shows the primary and secondary windings are wound in the counter clockwise direction and Figure 6(b) shows the secondary is wound in the clockwise direction. If the positive reference direction of either voltage is applied to one winding, the dotted end of the other winding is positive.

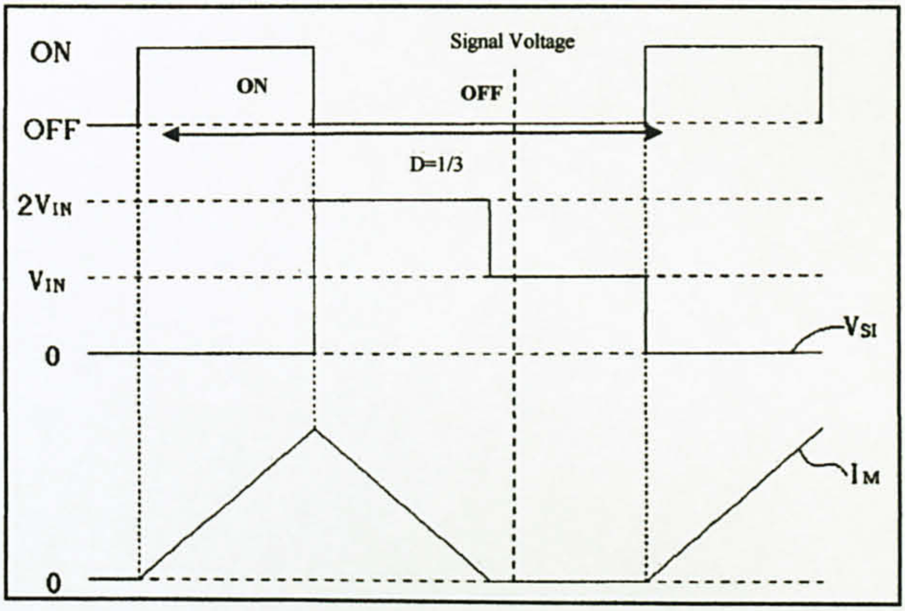


Figure 7: Timing diagram for tertiary winding reset circuit. [4]

Figure 7 shows the timing diagram for tertiary winding reset circuit. The top waveform represents the signal voltage in rectangular pulse, following with voltage across switch, V_{S1} and magnetizing current, I_M. By assuming the duty cycle, D=1/3, magnetizing current, I_M only needs one-half of the time necessary to release the magnetizing energy during the OFF period.

When the magnetizing energy is fully discharged, the voltage drop at the primary winding is rated at zero. At the same time, value of switch, V_{S1} decreases from $2V_{IN}$ to V_{IN}.

The magnetizing energy has to be fully discharged before the next turn ON period. Maximum duty cycle of the transformer is limited within 0.5.

2.6.2 RCD Reset Circuit.

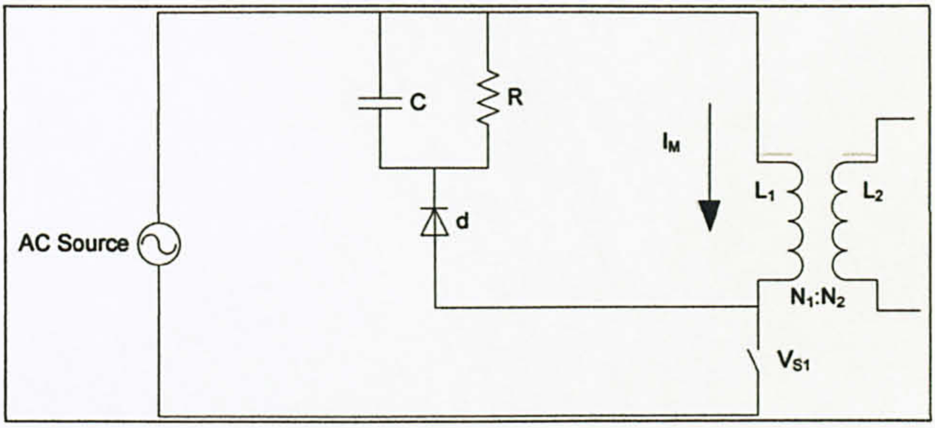


Figure 8: RCD reset circuit.

Figure 8 shows RCD reset circuit. RCD reset circuit consists of a resistor, *R* attached in a parallel position with a capacitor, *C*. Then, both of these components are connected in series with a diode, *d* and attached to the primary winding of the transformer.

The internal magnetic field of the transformer is reset by magnetizing inductor via RCD reset circuit when the diode, *d* of RCD reset circuit is turn ON. The internal magnetic field is reset until the next ON period.

Resistor is a power-consuming element. When RCD resets magnetizing energy, the resistor, R will transform part of magnetizing energy into heat. Resistor dissipates and changes parts of magnetizing energy into heat simultaneously when the inner magnetizing field of transformer is reset. The dissipated energy cannot be retrieved and efficiency of the transformer was reduced.

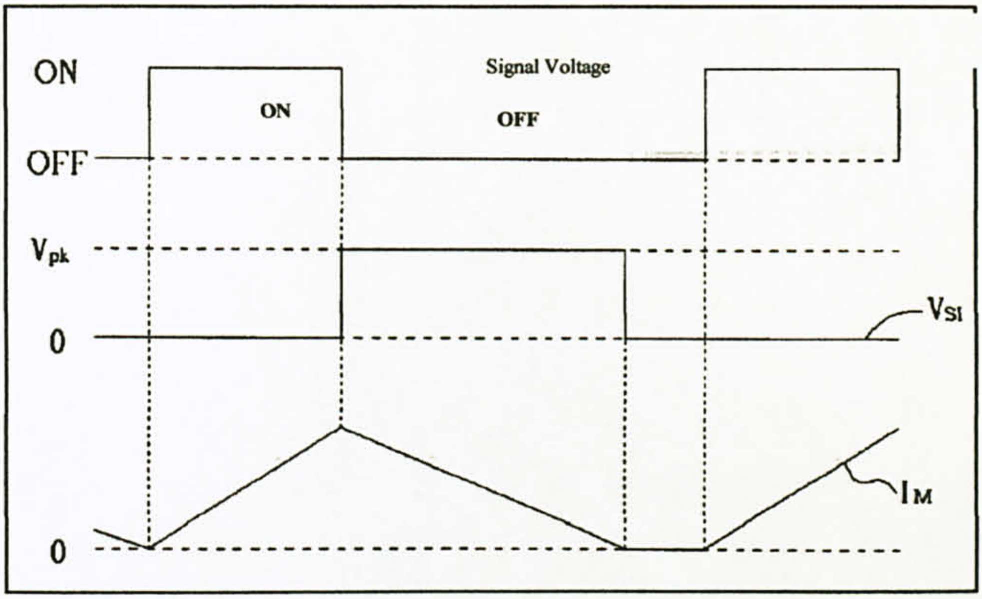


Figure 9: Timing diagram for RCD reset circuit. [4]

Figure 9 shows timing diagram for RCD reset circuit. The magnetizing current, I_M through magnetizing inductor, L_l is reset during switch, V_{SI} is turn OFF.

2.6.3 *Resonant Reset Circuit.*

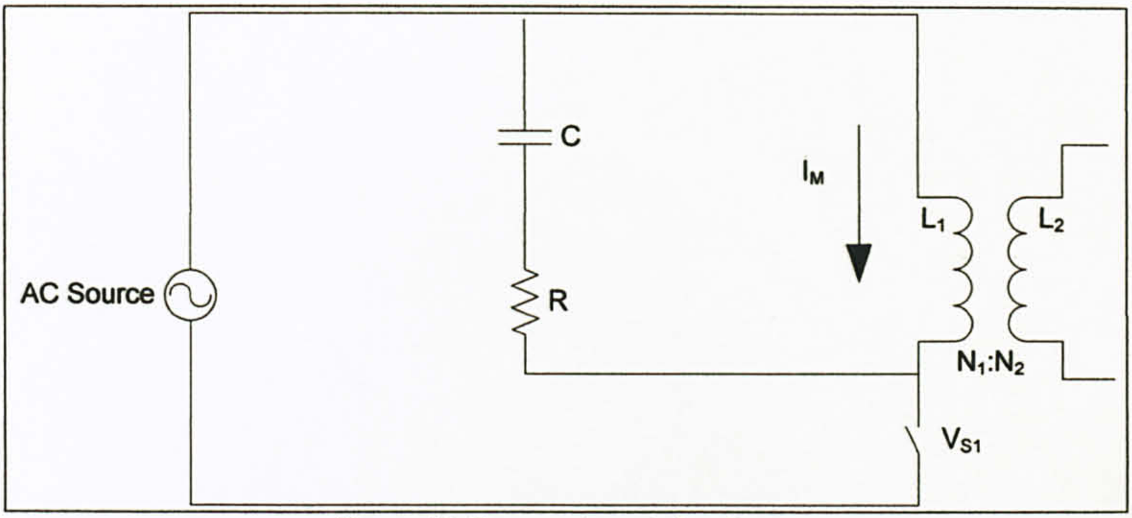


Figure 10: Resonant reset circuit.

Figure 10 shows resonant reset circuit. A capacitor, *C* is connected in series with the resistor, *R*. Both of these components then connected to the primary winding of the transformer in parallel position.

The loop comprised of magnetizing inductor, L_1, resistor, *R* and capacitor, *C* is refereed as LC resonant loop. The magnetizing current discharges through this LC resonant loop [4].

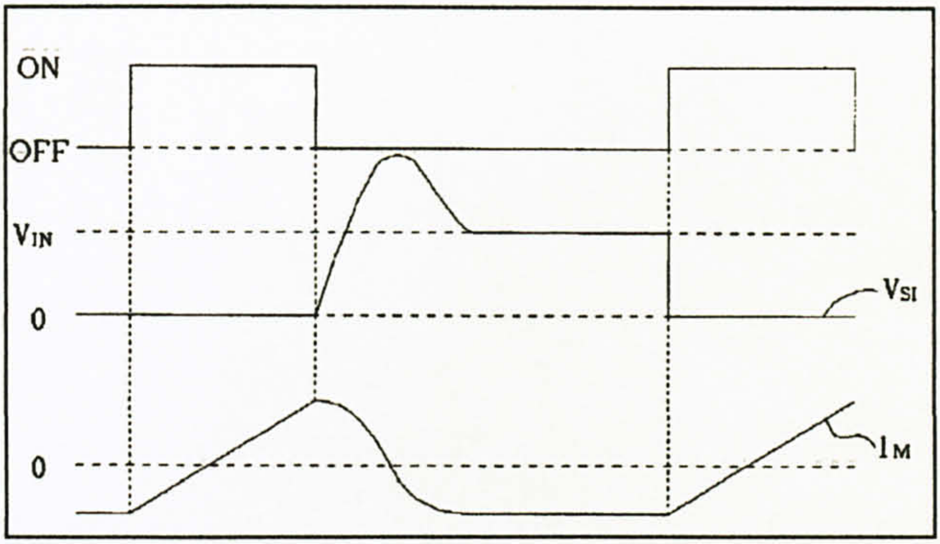


Figure 11: Timing diagram for resonant reset circuit. [4]

Figure 11 shows the timing diagram for resonant reset circuit. Transformer charges the magnetizing inductor during turn ON period. During OFF period, the magnetizing energy is slowly reset until the next turn ON period.

The operating efficiency of the transformer is enhanced by resetting it internal magnetic via the LC resonant circuit, however the resonance caused by the LC resonant circuit will form a harmonic wave. This harmonic wave can cause an unexpected high voltage across the switch, V_{SI}. An improvement of resonant reset circuit will be discussed in Section 2.7.

2.7 Improvement of Resonant Reset Circuit

In order to overcome the above situation some improvement has been made in terms of circuit design and configuration of a forward type DC-DC converter with resonant circuit. Due to the simplicity of the structure, forward type topology is used in DC-DC converters [6].

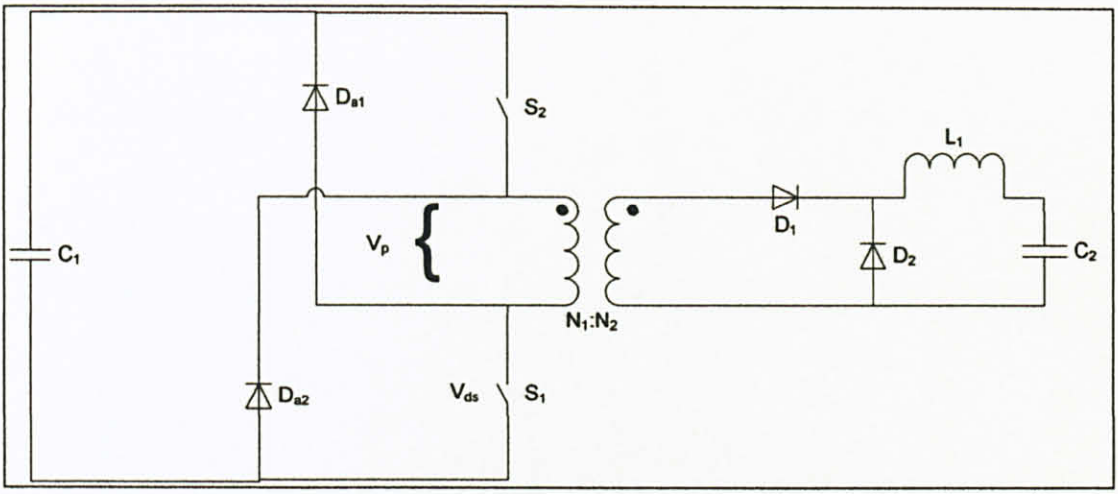


Figure 12: Dual switch forward DC-DC converter

Figure 12 shows typical dual switch forward DC-DC converter. Dual switch forward topology is used to reduce the voltage stress of main switches in high input voltage operation. However, the dual switch forward topology is not suitable for wide input voltage operation as the limitations of magnetic reset mechanisms. On the primary side, two switches, S_1 and S_2 were applied.

The transformer on the primary winding is connected to the input voltage after switches turn ON. Then, the energy is delivered from source to load. Magnetizing current passes by two clamping diodes which were denoted as D_{a1} and D_{a2} after two switches turn OFF. The input voltage is applied to the primary winding reversely and the magnetizing current is reset to zero [4]. The switches only endure the voltage stress of the input when the drain-to-source voltage of the switches is clamped to the input voltage.

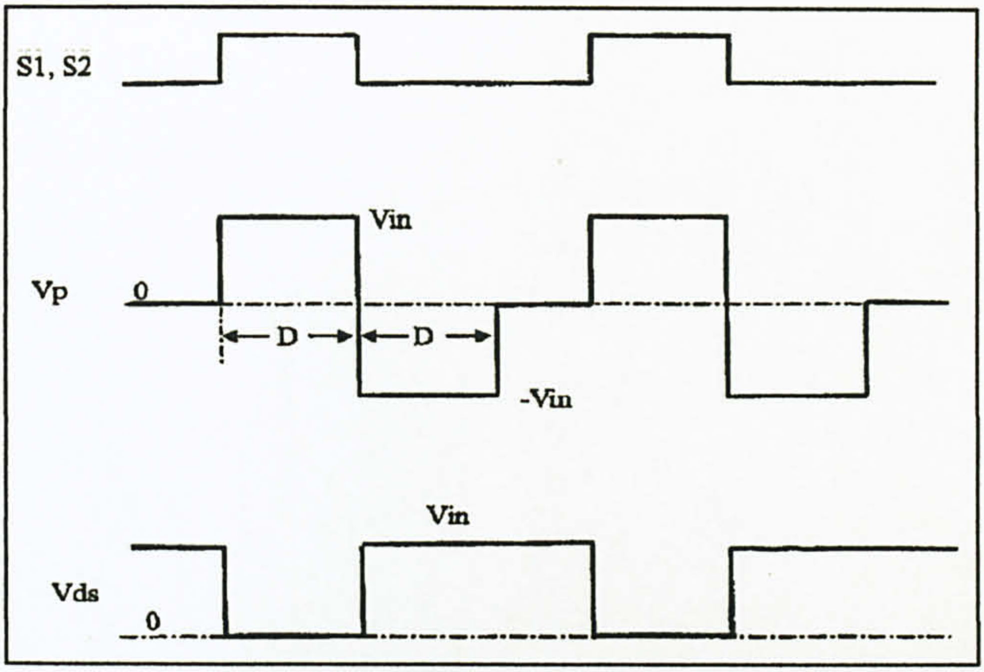


Figure 13: Waveform of a dual switch forward DC-DC Converter. [6]

Figure 13 shows waveform generated from dual switch forward DC-DC Converters. In other words, to keep the voltage-second balance for the transformer, the reset time must equal to the turn-on time of the switches as the reset voltage is equal to the input voltage. For low input operation, the maximum switching duty cycle is limited to less than 50%. The duty cycle becomes small and the performance of converter deteriorates when then input voltage is increase.

Increase in duty cycle over 50% can reduce the conduction loss of the primary side and lowering the voltage stress of the secondary side. The duty cycle can be over 50% if the resonant mechanism provide in the forward converter because reset voltage can be higher than the input voltage.

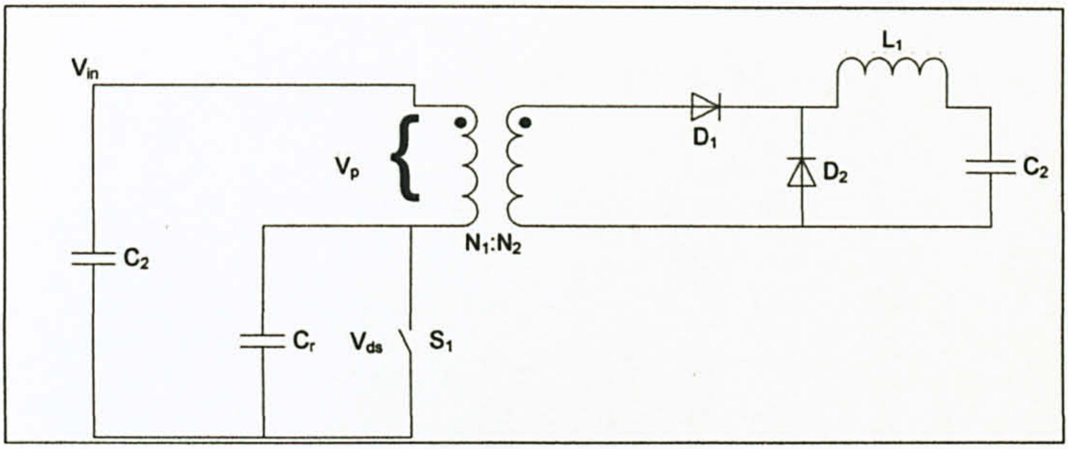


Figure 14: Single-ended forward DC-DC converter with resonant reset

Figure 14 shows schematic diagram of single-ended forward DC-DC converter with resonant circuit. There is only one switch S_1 is connected in the transformer primary side and a resonant reset capacitor C_r is connected in parallel with S_1.

Transformer primary winding is connected to the input voltage V_{in} after the switch S_1 turn ON. Then the energy is delivered from source to load by the transformer coupling. Magnetizing current charges the resonant capacitor C_r, after switch S_2 turn OFF. This will increase the voltage of capacitor C_r and transformer core will be reset. The magnetizing current is reset to zero and voltage of primary winding remains zero due after a half of resonant period due to the cross conduction of the secondary rectifier. When the switch S_1 turns ON again, the voltage of capacitor C_r no longer maintain as the input voltage V_{in}. The capacitor will be discharged through S1 after switch S_1 is turn ON. The energy stored in the capacitor C_r in switch S_1. Power loss of switch S_1 is larger.

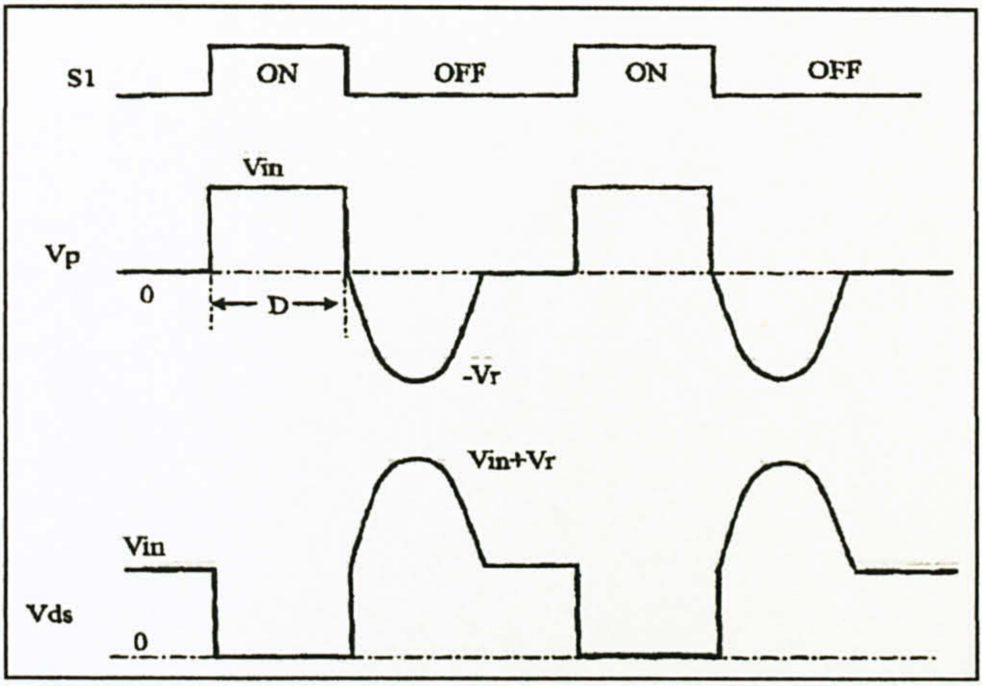


Figure 15: Waveform of single-ended forward DC-DC converter with resonant reset. [6]

Figure 15 shows waveform of single-ended forward DC-DC converter with resonant reset. There is only one switch, S_1 in the waveform. Primary voltage of transformer, V_p conducts during switch S_1 is turned ON.

2.8 Magnetic Circuit Switching

2.8.1 Principle of Magnetic Circuit Switch

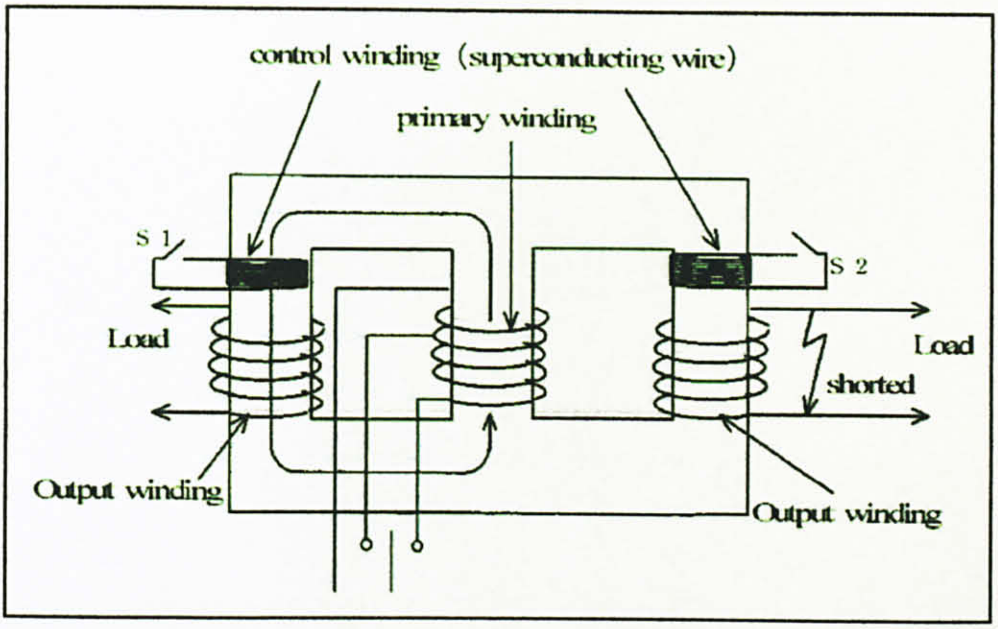


Figure 16: Principle of magnetic circuit switch [7]

Figure 16 shows magnetic circuit switch. Primary coil is wound on the central leg. Magnetic flux generated by the primary coil is divided to the left and right legs. There are load coil and the control coil (superconducting) are wound on each side leg.

Magnetic flux which goes through the leg with the shorted control coil is blocked by the ON/OFF operation of the superconducting control coil. The output voltage of the load which wound on the same leg becomes zero. Hence, by closing the control switch, the circuit breaking can be controlled.

2.8.2 *Switching Test*

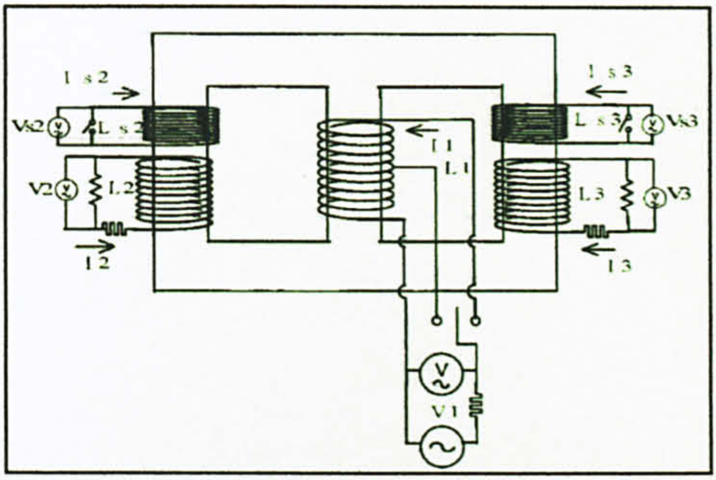


Figure 17: Experiment circuit for magnetic circuit switch [7]

Figure 17 shows experiment circuit for magnetic circuit switch. This experiment was conducted to confirm the switching principle. The voltage source is connected to primary coil, L_1. Left side output coil L_{s2}, was shorted [6].

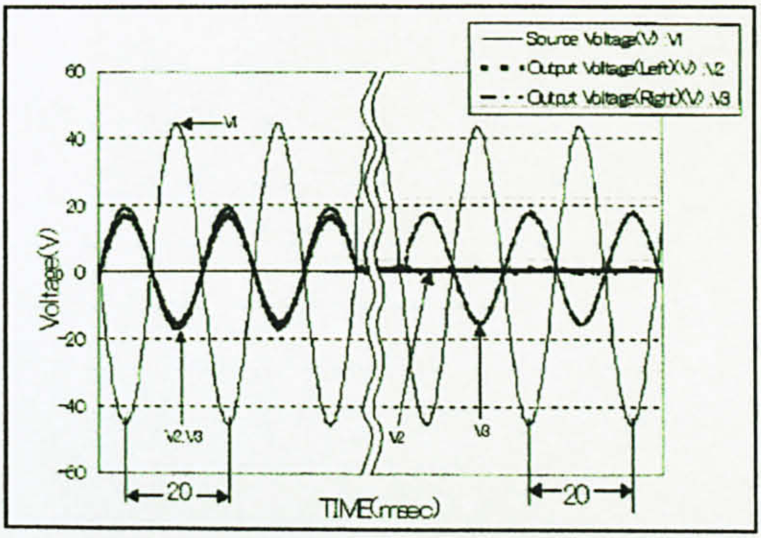


Figure 18: Voltage waveform in switching test [7].

Figure 18 shows voltage waveform in switching test. After a certain time we can see the output voltage, V_2 become zero [7].

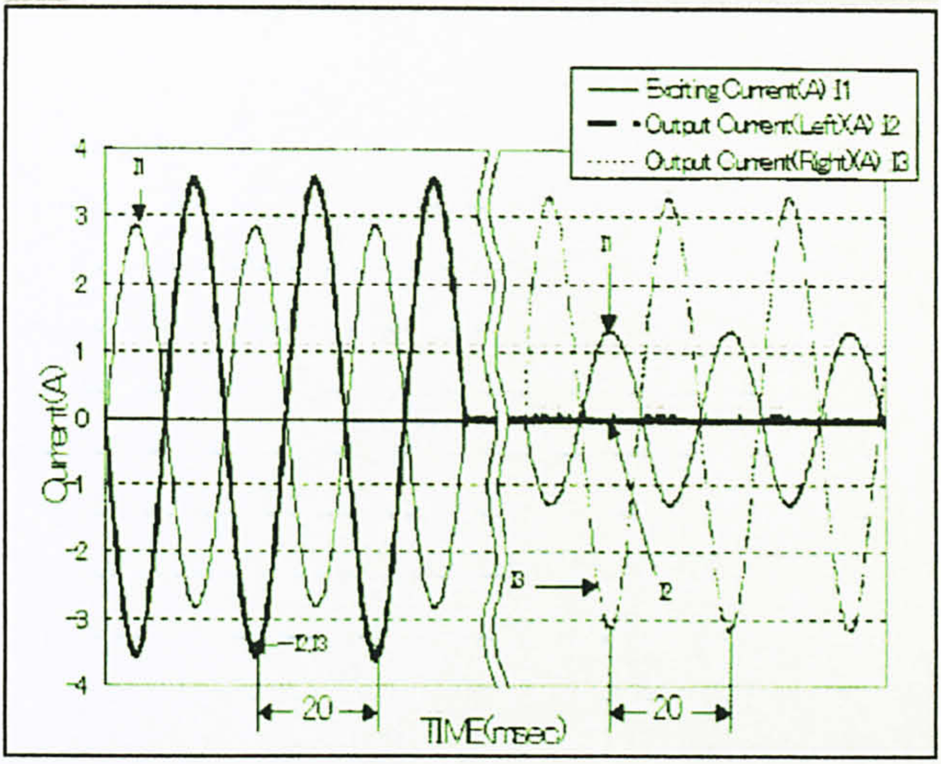


Figure 19: Current waveform in switching test [7].

Figure 19 shows current waveform in switching test. Output current, I_2 become zero. When control coil was shorted, both current and voltage become zero. Magnetic flux in the right side coil was blocked completely by the shielding current in the superconducting control coil [7].

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

This project basically is to design a magnetic reset circuit and simulation work. A lot of researches need to be done in order to get more information. The flowchart of methodology is shown in Figure 20.

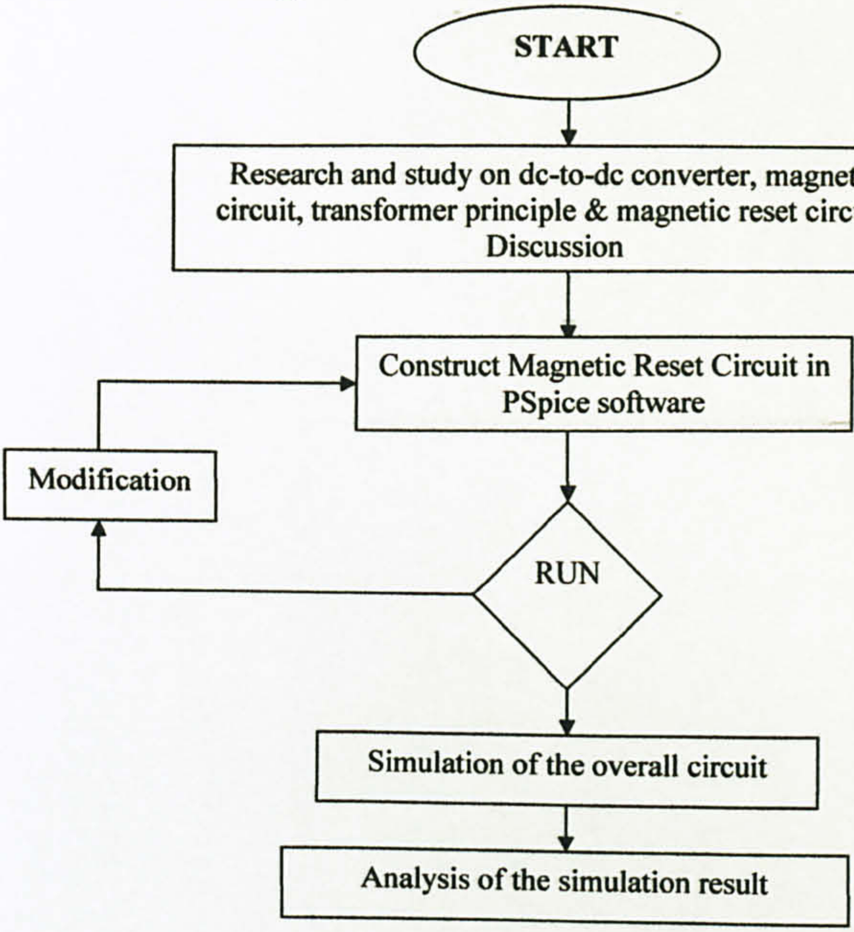


Figure 20: Methodology Approach

3.2 Tools and Equipment Required

3.2.1 Software

This project is based on research and simulation. There is no requirement for specific tools or equipment. The details about the software used which is PSpice software stated in Table 1.

Table 1: Details PSpice Software

Name Software	PSpice Schematics
Version	9.2.3
Build	247
Developer	Cadence Design System, Inc.

3.3 Conventional Transformer Circuit

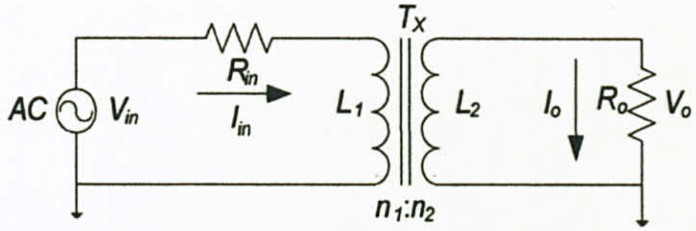


Figure 21: Conventional Transformer Circuit

Figure 21 shows the conventional transformer circuit without magnetic reset circuit. A common conventional transformer circuit is used as the test circuit for evaluating the performance of the different transformer circuit with modified parameters.

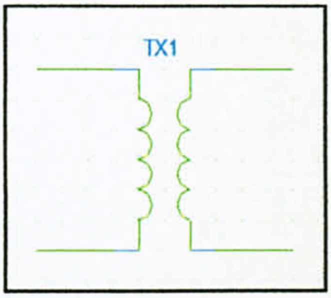


Figure 22: XFRM_LINEAR

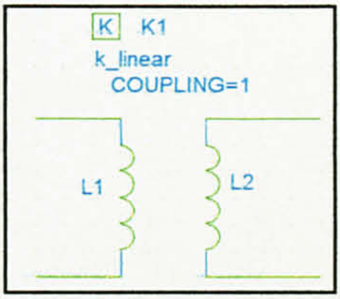


Figure 23: K_LINEAR

XFRM_LINEAR in Figure 26 or K_LINEAR in Figure 27 can be used to build the transformer in Pspice. AC Source power is represented by V_{in}. Input resistor, R_{in} must include in primary side since the AC Source power cannot be connected directly to the primary inductor, L_1.L_2 and R_o represented secondary inductor and output resistor/load respectively.

3.4 Transformer Circuit with Magnetic Reset Circuit

3.4.1 Secondary Side

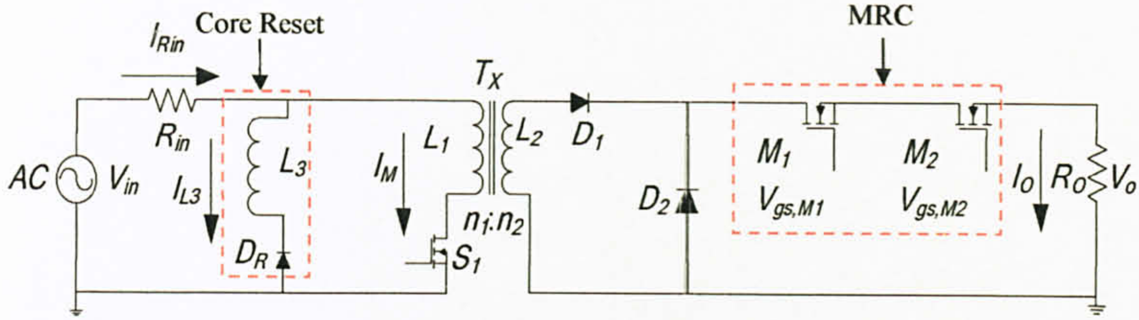


Figure 24: Proposed Transformer with MRC on Secondary Side

Figure 24 shows proposed transformer circuit with MRC on secondary Side. MRC is designed based on tertiary winding reset circuit [4]. In MRC there are two important parts to remove the induced effects in transformer which are core reset and magnetic reset circuit.

Core reset consists tertiary inductor, L_3 and reset diode, D_R. Core reset resets the magnetizing energy of transformer according to the ratio of windings between L_1 and L_3 [2]. Core reset also provides path for inductor to discharge the energy and smoother the induced waveform.

Two switches, M_1 and M_2 represented as an open circuit switch on secondary winding. M_1 and M_2 received the complimentary PWM signal of V_{pulse} from V_{M1} and V_{M2} respectively. In simple understanding, M_1 will turn ON whereby at the same time M_2 is turn OFF. Furthermore, the connection on the secondary side is not complete and automatically current cannot flow completely. M_1 and M_2 also known as magnetic reset circuit since it stop induced current from flowing to the load, R_o. In addition, no induced effects produced at the load and secondary inductor, L_2 can be used as another purposes.

3.4.2 *Primary Side*

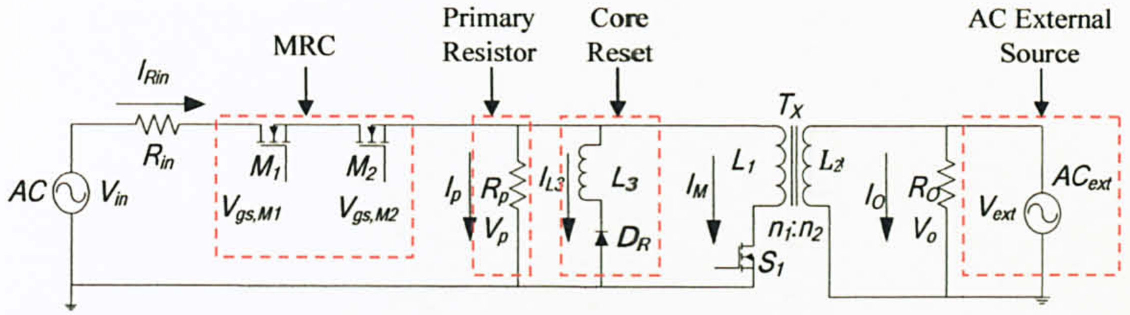


Figure 25: Proposed Transformer with MRC on Primary Side

Figure 25 shows the proposed transformer circuit with magnetic reset circuit on primary side. This circuit consists three main parts which are magnetic reset circuit, core reset and external AC source.

As mention earlier, magnetic reset circuit provided an open circuit to the primary side. Magnetic reset circuit is placed on the primary side to test where induced effects are presented or not. Core reset basically functioning to reset magnetizing energy of primary inductor, L_1.

External AC Source, V_{ext} need to supply secondary side since the main supply from primary side is cut-off. Primary resistor, R_1 is attached to the primary side to test whether secondary inductor can induce effects to the primary side or not.

All the values of the calculations and parameters of all transformer circuits will be discussed in Section 3.5.

3.4.3 MRC with Clipper

Although MRC removed the induced effects at the secondary side, there are still small induced effects presented at the load. A clipper is added to respective side in order to improve the capability of MRC to reset induced effects [4].

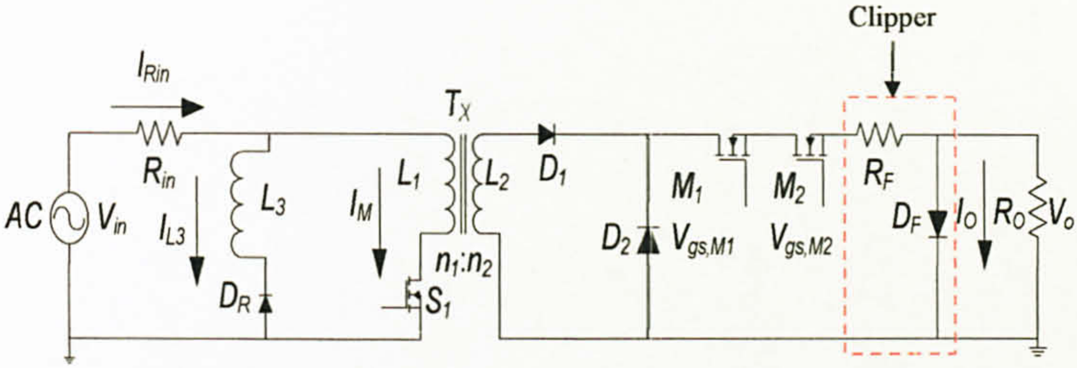


Figure 26: Improved MRC on Secondary Side with adding Clipper

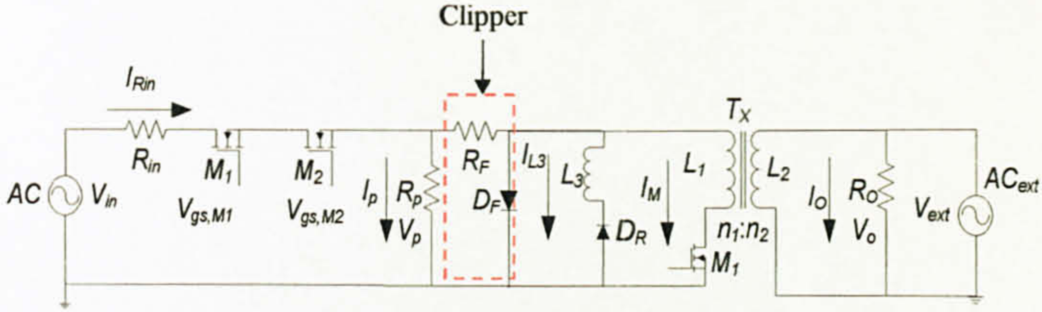


Figure 27: Improved MRC on Primary Side with adding Clipper

Figure 26 and Figure 27 shows clippers was introduced to the secodary side. Clippers used to reduce the leakage current, remove unwanted signal and make output response more faster.

3.5 Calculations and Operating Parameters Values

For transformer type, the step down transformer was chosen.

N_1=14, N_2=1 and L_1=10 mH are assumed to determined the value of L_2.

$$\frac{N_2}{N_1} = \sqrt{\frac{L_2}{L_1}} \qquad (4)$$

Equation (4) shows relationship between number of winding and value of inductor. By using the above formula, the value L_2 is 51 μH. Meanwhile, $L_3 \geq L_1$ [4]

Table 2: Operating Parameter Values

Parameter Values	Conventional Transformer	Transformer with MRC in Secondary	Transformer with MRC in Primary
V_{in}	VOFF=0, FREQ=1 Meg, VAMPL=170	VOFF=0, FREQ=1 Meg, VAMPL=170	VOFF=0, FREQ=1 Meg, VAMPL=170
V_{ext}	-	-	VOFF=0, FREQ=1 Meg, VAMPL=170
R_{in}	1 Ω	1 Ω	1 Ω
R_o	1 kΩ	1 kΩ	1 kΩ
R_F	-	1 kΩ	1 kΩ
L_1	10 mH	10 mH	51 μH
L_2	51 μH	51 μH	51 μH
L_3	-	10 mH	10 mH
S_1, M_1, M_2	-	IRF 250	IRF 250
D_1, D_2, D_R, D_F	-	1N6392	1N6392

Table 2 shows the important operating parameter values for three different circuits. Simulation results and analysis will be discussed in Chapter 4.

V_o for calculation value can be calculated using equation (5) below:

$$\frac{V_o}{V_{in}} = \frac{N_2}{N_1} \quad (5)$$

Table 3: Parameter setting for V_{pulse}

Parameters	**$^*V_{M1}$**	**$^*V_{M2}$**	**$^*V_{S1}$**
	Value	**Value**	**Value**
V_1	0 V	0 V	0 V
V_2	5 V	5 V	5 V
Time Delay, T_D	0 s	500 ns	500 ns
Rise Time, T_R	5 ns	5 ns	5 ns
Fall Time, T_F	5 ns	5 ns	5 ns
Pulse Width, *PW*	497 μs	497 μs	267 μs
Period, *PER*	1 μs	1 μs	1 μs

* Indicates V_{pulse} at respective switches

M_1, M_2 and S_1 are n-channel MOSFETs IRF 250 type. V_{pulse} has to be set according to the value which summarized in Table 3 to make all switches operated at desired value.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Simulation Results and Analysis

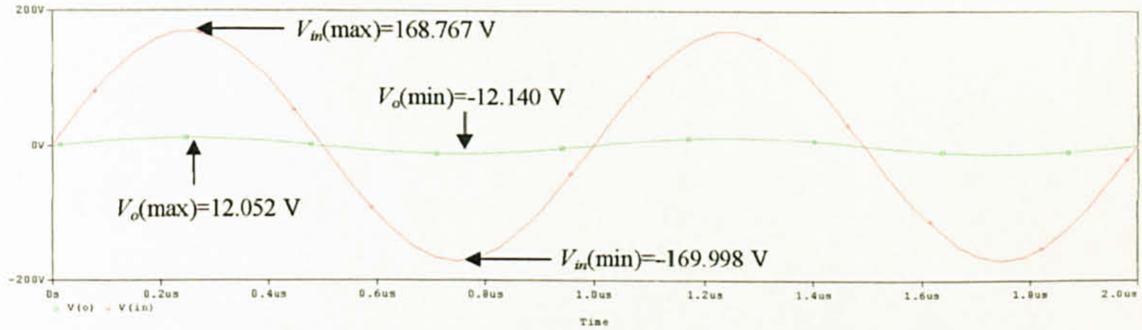


Figure 28: V_{in} and V_o of Conventional Transformer

Figure 28 shows input voltage, V_{in} and output voltage, V_o waveform of conventional transformer. Output voltage indicated lower value compare to input voltage which showed the transformer is step down transformer. Maximum and minimum voltage slightly different from calculated because of some resistance occur in active devices like resistor. Comparison between theoretical and simulation value presented in Table 4.

Table 4: Comparison Calculation and Simulation of Value V_{in} and V_o

	V_{in}		V_o	
	min (V)	max (V)	min (V)	max (V)
Calculation	-170.000	170.000	-12.143	12.143
Simulation	-169.998	168.767	-12.140	12.052
Error $\left(\frac{Calculation-Simulation}{Simulation}\right)\cdot 100\%$	0.2	0.72	0.02	0.02

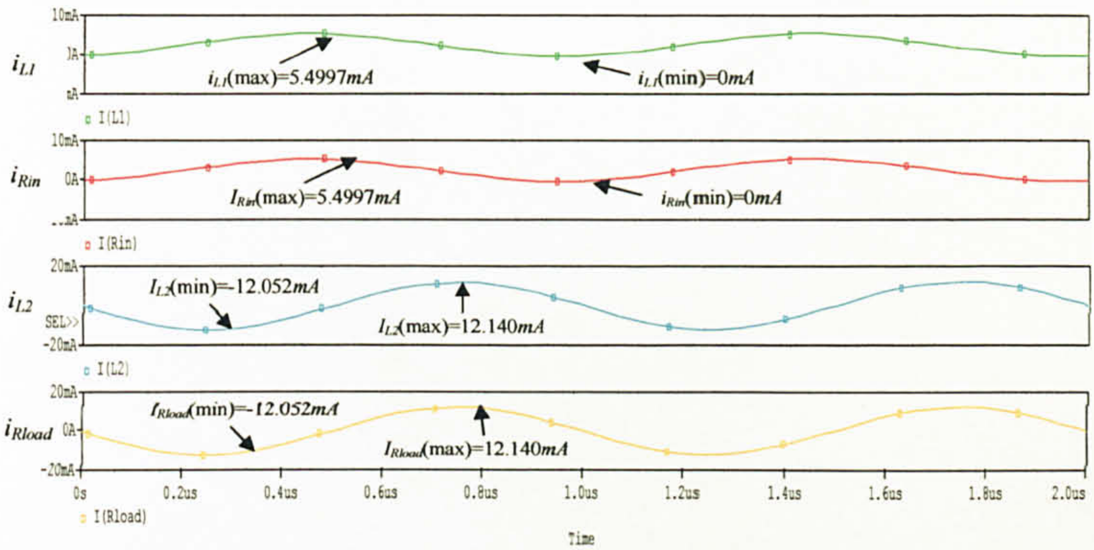


Figure 29: i_{L1}, i_{Rin}, i_{L2} and i_{Rload} of Conventional Transformer Circuit

Figure 29 shows inductor and resistor current of conventional transformer. The direction of current whether positive or negative depends on dot notation [2]. Inductor and resistor have same value and direction of current since they are in the same path respectively. These voltage and current waveform used as the reference for evaluating the performance of the different transformer circuits with MRC.

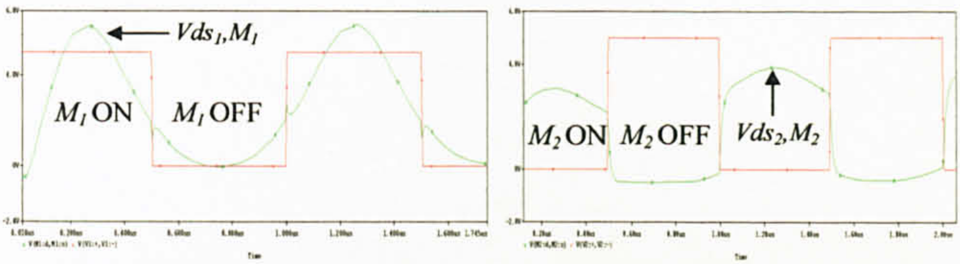


Figure 30: Operating waveform of M_1 and M_2

Figure 30 shows both switches, S_1 and S_2 operated at different period in one cycle. The switches behave like an open circuit. As the circuit is opened, the current cannot flow toward the load and hence produce the zero induced effects. However, there is slightly induced effect represented at the load because both switches got some time delay before it can operated.

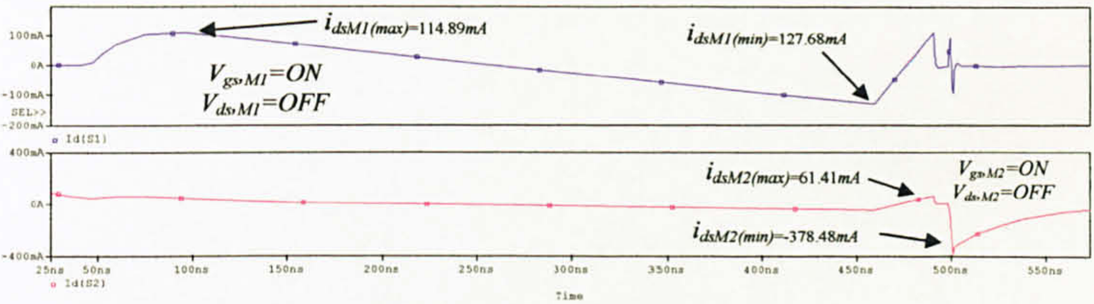


Figure 31: $i_{ds,M1}$ and $i_{ds,M2}$ of Proposed MRC Secondary Side

Figure 31 shows $i_{ds,M1}$ and $i_{ds,M2}$ of Proposed MRC Secondary Side. The current is read and measured at both MRC switches which are M_1 and M_2.

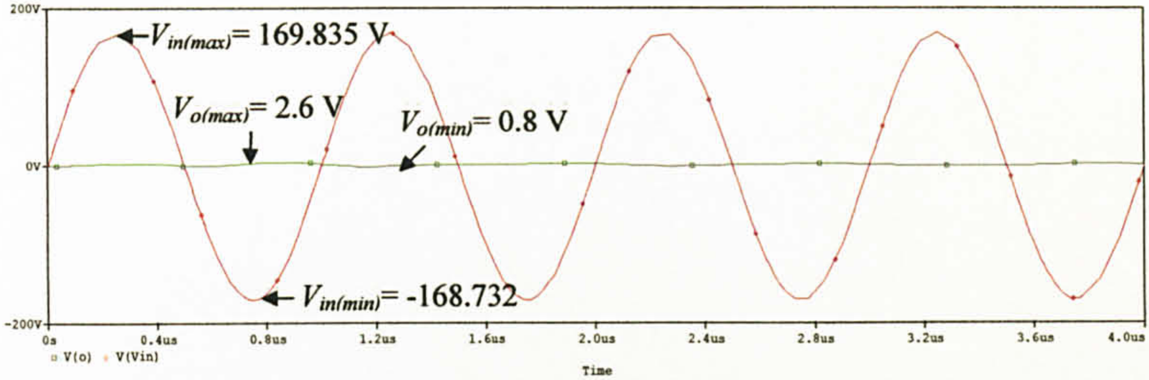


Figure 32: V_o and V_{in} of Proposed MRC on Secondary Side

Figure 32 shows input and output voltage waveform of proposed magnetic reset circuit. There are still some value of V_o represented at the load. There is some delay at the MRC and also some excess induced current which are not completely reset to zero value. In order to remove some excessive induced effects, some improvement has been made by adding a clipper to respective sides. This result will be discussed after MRC on primary side result.

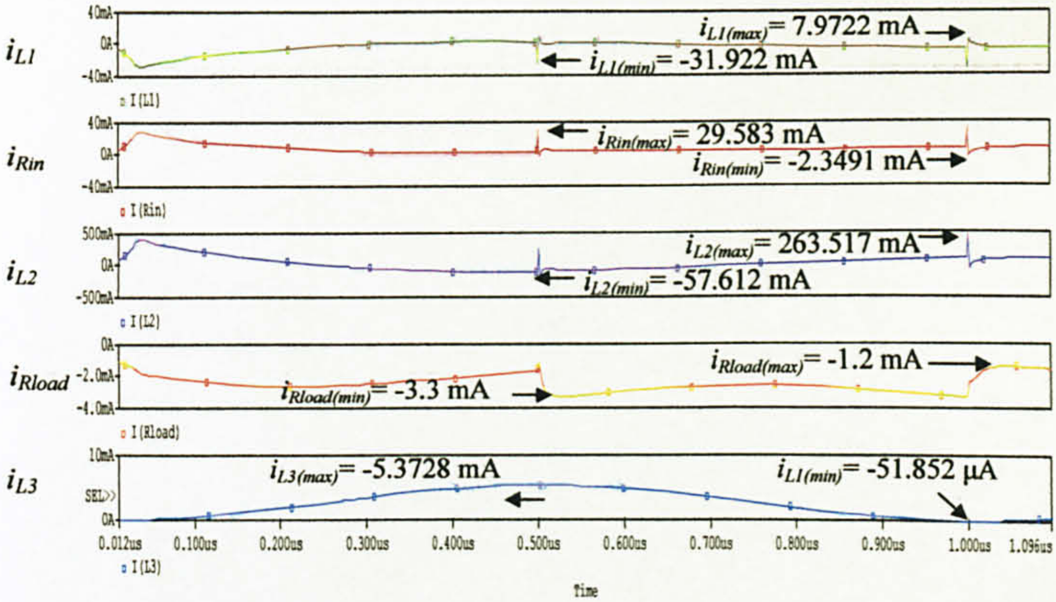


Figure 33: i_{L1}, i_{Rin}, i_{L2}, i_{Rload} and i_{L3} of Proposed MRC on Secondary Side

Figure 33 shows i_{L1}, i_{Rin}, i_{L2}, i_{Rload} and i_{L3} of Proposed MRC on Secondary Side. There are also some induced current, i_{Rload} represented at the load which caused so induced effect of voltage. However, the value of current represented is small and can be removed using clipper.

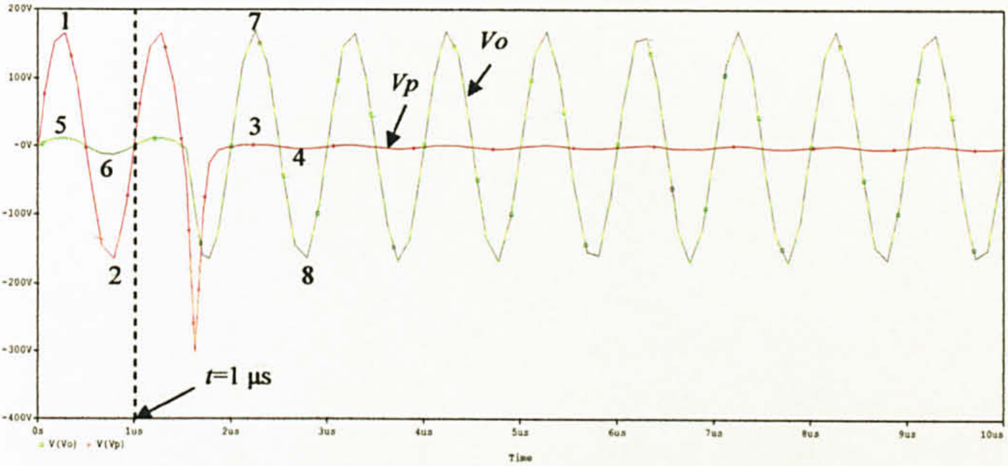


Figure 34: V_o and V_p of Proposed MRC on Primary Side

Figure 34 shows V_o and V_{in} of proposed MRC on primary side. The external voltage, V_{ext} is turns ON at the same time when MRC is operated. This procedure used to investigate is there induced voltage produced at primary side when V_{ext} is turn ON.

There are several number on the Figure 33 which indicated the important values of voltage before and after t=1 µs. As mention earlier, primary resistor, R_1 is inserted at primary side to investigate the performance of MRC in terms of resetting induced effects. The MRC is set to operate at t=1 µs together with external AC source, V_{ext}.

The important parameters and values are summarized in Table 5.

Table 5: Important Parameter Values of V_o and V_p

Point Number	Variables	Values
1	$V_{p(\max)} < 1\ \mu s$	165.020 V
2	$V_{p(\min)} < 1\ \mu s$	-165.028 V
3	$V_{p(\max)} > 1\ \mu s$	1.8092 V
4	$V_{p(\min)} > 1\ \mu s$	-3.0908 V
5	$V_{o(\max)} < 1\ \mu s$	11.785 V
6	$V_{o(\min)} < 1\ \mu s$	-11.785 V
7	$V_{o(\max)} > 1\ \mu s$	170.175 V
8	$V_{o(\min)} > 1\ \mu s$	-164.441 V

Table 5 shows the important values V_o and V_p. From the table we there are still induced effects in the primary side. However the value of induced effect in the primary side has been reduced from 165.020 V to 1.8092 V for maximum value and from -165.028 V to -3.0908 V for minimum value. This showed that MRC is operating properly to remove induced effects of the transformer. But some values still produced caused by time delay for MRC reset to turns ON,

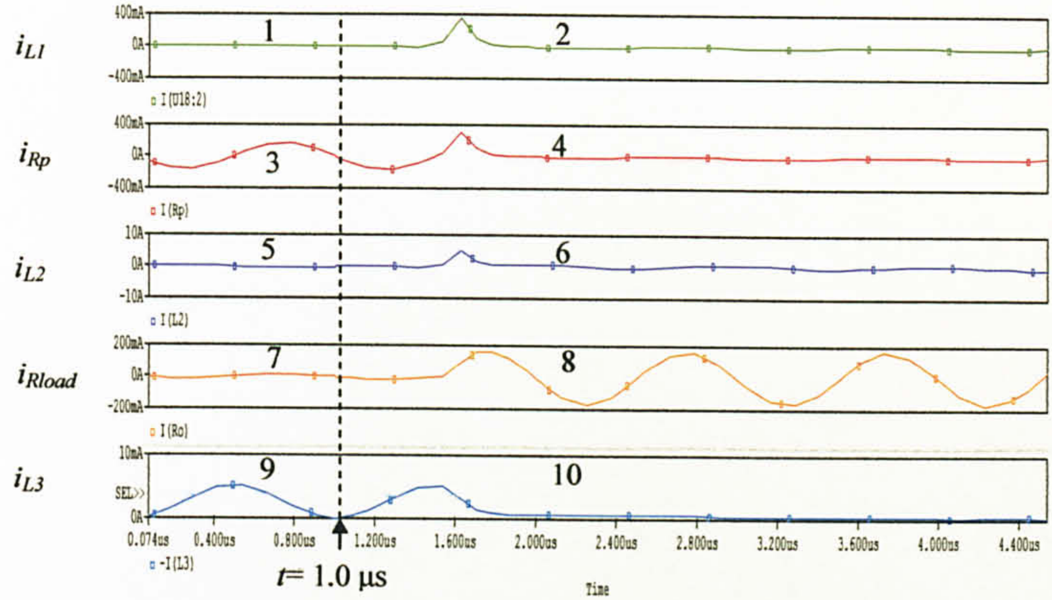


Figure 35: i_{L1}, i_{Rp}, i_{L2}, i_{Rload} and i_{L3} of Proposed MRC on Primary Side

Figure 35 shows current waveform for transformer with MRC on primary side. There are several numbers on the figure which showed that the section before and after MRC and V_{ext} are turn ON. The numbers indicated the maximum and minimum value of respective current produced before and after t=1 µs.

MRC attached at primary side reduce value of primary current, i_{Rp}. MRC takes some time to reset the induced current. This is caused by switching delay at the MOSFET. However, MRC can reduced the induced current at primary side from maximum value 165.028 mA to 3.0908 mA and minimum value from -165.064 mA to 1.9184 mA.

The other parameters are summarized in Table 5.

Table 6: Important Parameter Values of i_{L1}, i_{Rp}, i_{L2}, i_{Rload} and i_{L3}

Point Number	Variable	Values
1	$i_{L1} < 1$ µs	*max*=5.2812 mA *min*=-34.898 µA
2	$i_{L1} > 1$ µs	*max*=1.885 mA *min*=--1.9876 mA
3	$i_{Rp} < 1$ µs	*max*=165.028 mA *min*=-165.064 mA
4	$i_{Rp} > 1$ µs	*max*=3.0908 mA *min*=1.9184 mA
5	$i_{L2} < 1$ µs	*max*=11.631 mA *min*=-11.632 mA
6	$i_{L2} > 1$ µs	*max*=911.669 mA *min*=-70.520 mA
7	$i_{Rload} < 1$ µs	*max*=11.785 mA *min*=-11.788 mA
8	$i_{Rload} > 1$ µs	*max*=165.825 mA *min*=-170.175 µA
9	$i_{L3} < 1$ µs	*max*=51.1334 mA *min*=49.950 µA
10	$i_{L3} > 1$ µs	* 378.643 µA

* Indicate that current at L_3 always decreasing due to tertiary winding reset.

Table 6 shows the other parameter values of current produced in MRC on primary side.

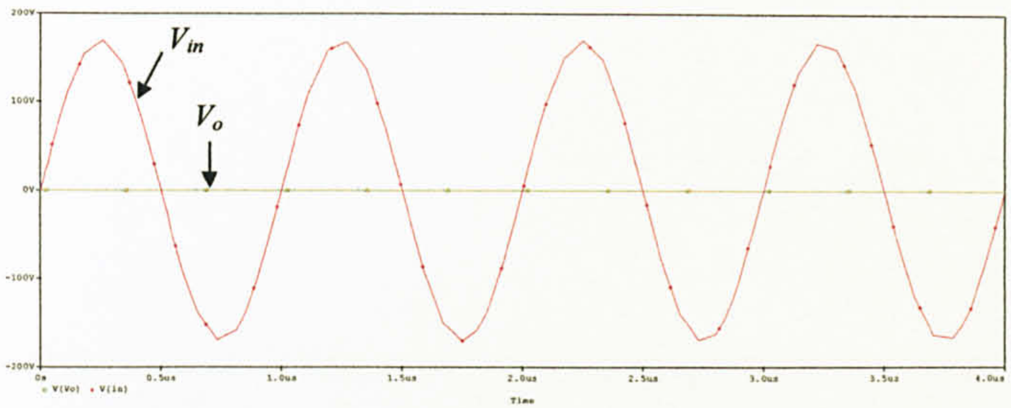


Figure 36: V_o and V_{in} of Proposed MRC on Secondary Side with Clipper

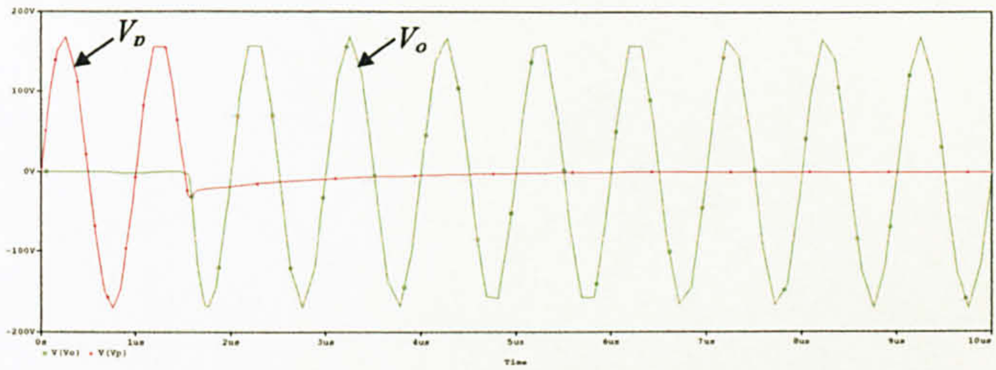


Figure 37: V_o and V_p of Proposed MRC on Primary Side with Clipper

Figure 36 and Figure 37 show the voltage waveform after added with clipper on their respective sides. From the figure, the clipper chop and make the amplitude of wave form goes to zero value. Figure 36 shows MRC with clipper reset the induced voltage immediately when MRC is turns ON. Figure 37 shows MRC with clipper take some time to reset the induced effect on primary side. This is because some delay of MRC and switching time between two AC source power.

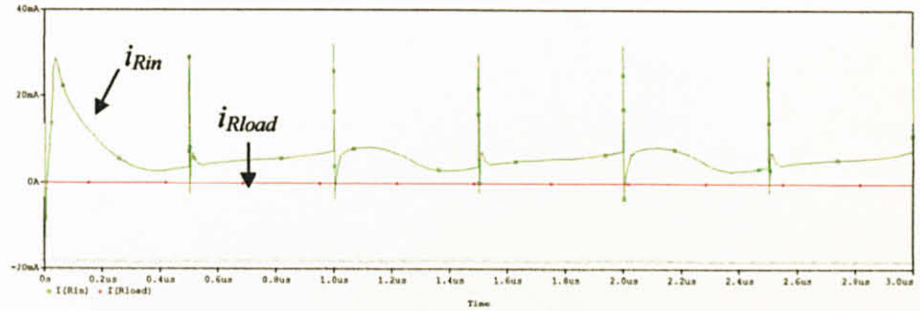


Figure 38: i_{Rload} and i_{Rin} of Proposed MRC on Secondary Side with Clipper

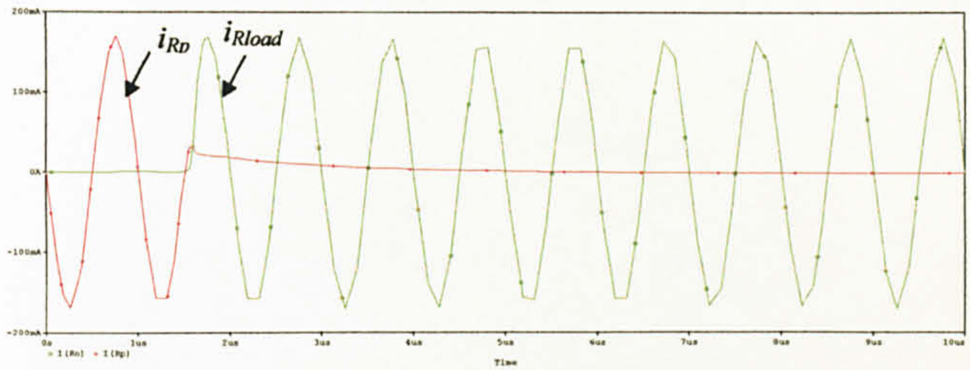


Figure 39: i_{Rload} and i_{Rp} of Proposed MRC on Primary Side with Clipper

Figure 38 and Figure 39 show waveform of current for MRC using Clipper. Similar to voltage waveform, the current is reset to approximate zero value with clipper. However the MRC on primary side with clipper have some delay before it can reset the current.

After resetting induced effects of transformer, both inductors can be used effectively as voltage and current path without inducing any current or voltage to respective winding. The values of all induced effects from conventional transformer and transformers with MRCs are summarized and analyzed in Table 6 and Table 7.

Table 7: Comparison Induced Effects of all Circuits

	V_p/V_{in}	V_o	i_{Rin}/i_{Rp}	i_{Rload}
Figure 21	max= 168.77 V min= -169.00 V	max= 12.05 V min= -12.14 V	max=5.5 mA min=0 mA	max=12.1mA min= -12.1 mA
Figure 24	max= 169.84 V min= -168.73 V	max= 2.06 V min= -0.8 V	max=18 mA min=0.5 mA	max=0.47 mA min=-3.0 mA
Figure 25	max= 1.8 V min= -3.1 V	max= 170 V min= -164 V	max=3.1 mA min=1.9 mA	max=165 mA min=-170 mA
Figure 26	max= 169.84 V min= -168.73 V	0.0 V	max=18 mA min=0.5 mA	0.01 mA ≈ 0.0 mA
Figure 27	57 mV ≈ 0.0 V	max= 170 V min= -169 V	-57 µA ≈ 0.0 mA	max=169mA min=167 mA

Table 7 shows comparison between all circuits which are conventional circuit, circuit with MRC and also circuit with MRC and also clipper. From the table, the induced effects can be removed using MRC and the clippers also help MRC to removed or block induced effects in respective windings.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

Magnetic reset circuitry is designed to reset the induced effects in linear transformer applications. In other word, both sides of windings can be used effectively as voltage and current path without inducing any current or voltage to respective winding.

MRC was designed and simulated successfully and achieved the objective of this project. The results show that the induced effects were reset to zero value. Now, the respective winding can be used as a voltage and current part without inducing other winding.

5.2 Recommendation

There are basically three techniques in resetting magnetizing energy [4]. RCD reset circuit, resonant reset circuit and improvement resonant reset circuit [5] are also relevant for resetting magnetizing energy and can also design and simulate in PSpice software.

REFERENCES

[1] Issa Batarseh, "Introduction", *Power Electronics Circuits* (2nd ed.), John Wiley & Sons, Inc., Ch. 1, pp 10 to 11, 2004

[2] Issa Batarseh, "Introduction to Magnetic Circuits", *Power Electronics Circuits* (2nd ed.), John Wiley & Sons, Inc., Appendix A, pp 494 to 519, 2004

[3] Stephen J. Chapman, "Transformers", *Electric Machinery Fundamentals* (2nd Ed.), Mc Graw Hill, Ch. 2, pp 65 to 86, 2005

[4] Guo-Kiang Hung, "Circuitry for Resetting Magnetic Field of Transformer", *United State Patent,* Patent No: US 6,744,642 B2, pp 1 to 13, Jun 2004

[5] MAXIM, "Designing Single-Switch, Resonant-Reset, Forward Converters", *Application Note 3983,* pp 1 to pp 10, Mar 20, 2007.

[6] Guisong Huang, Yilei Gu, Zhizheng Liu & Alpha J. Zhang, " Resonant Reset Dual Switch Forward DC-to-DC Converter, *United State Patent Application Publication,* pp. 1 to 15, March 2002

[7] Hiromitsu Mizutori, Akira Ninomiya, and Takeshi Ishigohka, "Magnetic Switching Element with Superconducting Coil", *IEEE Transaction on Applied Superconductivity, Vol 12, No.1,* pp. 859 to 862, March 2002

[8] Issa Batarseh, "Isolated Switch-Mode dc-to-dc Converters", *Power Electronics Circuits* (2nd ed.), John Wiley & Sons, Inc., Ch. 5, pp 209 to 238, 2004

[9] Issa Batarseh, "Soft-Switching dc-dc Converters", *Power Electronics Circuits* (2nd ed.), John Wiley & Sons, Inc., Ch. 6, pp 263 to 265, 2004

[10] N.Z. Yahaya, K.M. Begam and M. Awan, "Investigation of High Frequency Effects on Soft-Switching Synchronous Rectifier Buck Converter", *IEEE Symposium on Industrial Electronics And Application (ISIEA 2009),* October 4-6, 2009, pp 524 to 528, 2009

[11] Charles K. Alexander and Matthew N. O. Sadiku, "Frequency Response", *Fundamentals of Electric Circuit Third Edition*, Mc Graw Hill, Ch. 14, pp 613 to 655, 2007

[12] Ionel Dan Jitaru and Alexandru Ivascu, "Increasing The Utilization of the Transformer's Magnetic Core by Using Quasi-Integrated Magnetics", HFPC Power Conversion, *ROMPOWER Inc.*, pp 238 to 252, September 1996

[13] Mr Fluids, "Magnetic Circuit Design", *LORD Material Division*, pp 1 to 4, 1999

APPENDICES

Appendix A: Gantt chart for FYP I

Activities/Milestone \ Week Number	1	2	3	4	5	6	7	8	9		10	11	12	13	14	15
	20/7 – 24/7	27/7 – 31/7	3/8 – 7/8	10/8 – 14/8	17/8 – 21/8	24/8 – 28/8	31/8 – 4/9	7/9 – 11/9	14/9 – 18/9	MID-SEMESTER BREAK	28/9 – 2/10	5/10 – 9/10	12/10 – 16/10	19/10 – 23/10	26/10 – 30/10	2/11-6/11
Confirmation on Title Selection	■	■														
Literature Review		■	■	■	■	■	■	■	■		■	■	■	■	■	■
Preparation and Submission Preliminary Report				■												
Preparation and Submission Logbook						■										
Preparation and Submission Progress Report								■								
Preparation and Submission Draft Report													■	■		
Preparation and Submission Interim Report														■	■	
Oral Presentation																■

Appendix B: Gantt chart for FYP II