

Switching of Circuit for Testing Performance of the Secondary Side of Core Transformer

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Abstract- This project is to design switching of circuit for testing performance of the secondary side core transformer. The MATLAB simulation, PSIM simulation and the hardware implementation did in order to test the switch can be function or not. From the simulation by PSIM software the switch will be function to ON and OFF the switch with depend on the cycle of the degrees were set up in the circuit. The modeling and simulation of SPMC were used MATLAB/Simulink and PSIM simulation set to predict the behaviour. As a conclusion the switch in the PSIM simulation will producing the B-H curve from it operation in the circuit. Then the result of simulation from the PSIM software can be considered used in order to test the performance at the secondary side of the core transformer.

Keywords: Core Transformer, Pulse Width Modulation (PWM), Sinusoidal Pulse Width Modulation (SPWM), MATLAB/Simulink (MLS), PSIM Simulation.

1. INTRODUCTION

In electronics, a switch is an electrical component which can break an electrical circuit, interrupting the current or diverting it from one conductor to another. The most familiar form of switch is a manually operated electromechanical device with one or more sets of electrical contacts. Each set of contacts can be in one of two states: either 'closed' meaning the contacts are touching and electricity can flow between them, or 'open', meaning the contacts are separated and no conducting. The switch needs in order to operate the electronic transformers. In the electronic transformer have a core which it is the main part of the electronic transformer [2]. In testing performance of the core, the reversal method was used for the switching of the circuit to test the

performance of the core. Core is the main part of the electronic transformer. The composition of the transformer core depends on voltage, current and frequency. Commonly used core materials are air, ferrite, soft iron and steel. Iron core transformers are usually used when the source frequency is low (below 20 Khz). The iron core transformer provides better power transfer than the air core transformer. The performance of the transformer is affected by the characteristics of the material in the core. The core loss in transformer consist Hysteresis loss and Eddy current loss. The value of losses is depending on the area of the B-H curve. By measuring the area of the hysteresis loop so obtained by means of a planimeter and expressing the area in B-H units of the area, the hysteresis loss for the material may be obtained. Since hysteresis loss per cycle per cubic meter, in joules is equal to area of loop in B-H units as shown in Eqn. 1.

$$\text{Hysteresis loss} = \text{Area of loop in B-H units} \dots \text{Eqn. (1)}$$

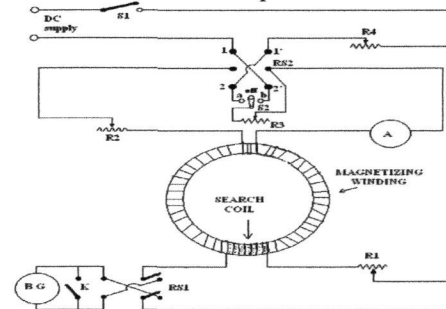


Figure 1: Circuit for testing core transformer

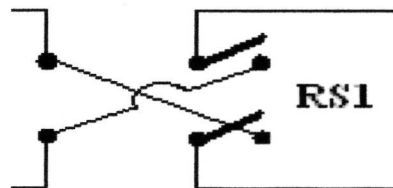


Figure 2: Switching circuit of RS1 to test performance secondary side of core transformer

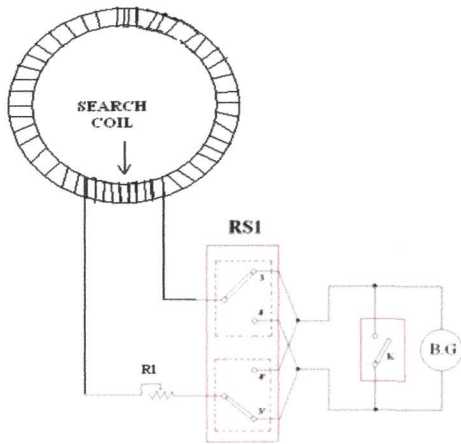


Figure 3: Modified RS1 circuit to test the core transformer at the secondary part

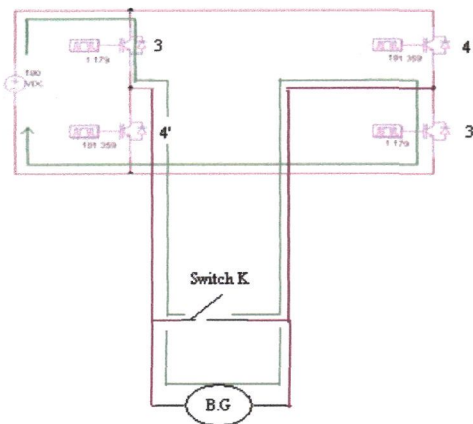


Figure 4: The switching operation using IGBTs when the switch IGBT 3 and IGBT 3' is ON in the RS1 circuit

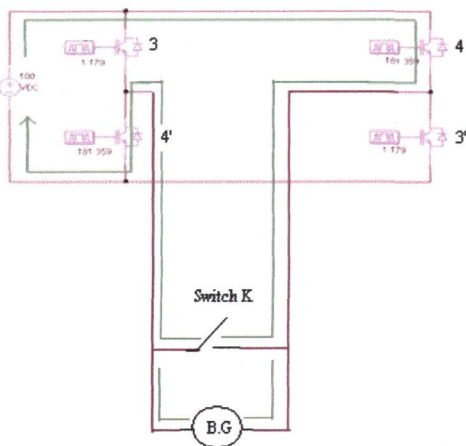


Figure 5: The switching operation using IGBTs when the switch IGBT 4 and IGBT 4' is ON in the RS1 circuit

From the Figure 1 showed the main testing circuit. It consists of the circuits on primary and secondary sides. The primary side of the main testing circuit contributes the magnetic flux and magnetic field to the secondary side of the core transformer after it

flow the magnetizing winding. The secondary side has switch RS1, will 'on' state when the current flow from IGBT 3 and IGBT 3' through the switch K and the Ballistic Galvanometer and the switch 'off' state when the current did not flow from IGBT 4 and IGBT 4'. After the certain time, the switch will 'on' state when the current flow through the IGBT 4 and IGBT 4' through the switch K and the Ballistic Galvanometer and the switch 'off' state when the current did not flow from IGBT 3 and IGBT 3'. The process in order to get the B-H curve started when the current applied in the magnetizing winding is increased from zero to some reasonably high value. It will be found that it shape is as shown by the portion A. After that, the current is reduced gradually to zero again, after some flux density B_{max} has been attained, the curve for descending values of H takes the form AD. Before that, reduction in flux density $-\Delta B$ is obtained from the galvanometer throw and hence the point C on the loop obtained. The flux density B_r remaining in the iron when H is again zero is referred to as the "residual magnetism". Since H is now zero, $B_r = J_r$ where J_r is the intensity of the magnetization left in the iron when the magnetizing force is removed. The residual flux density, after magnetization up to saturation point, is referred to as the "remanence" of the iron. If the direction of the magnetizing current is now reversed, and gradually increased in this reverse direction until a flux density $-B_{max}$ is again obtained, the curve follows the line DEF. The negative value of H required to reduce the residual flux density to zero, namely OE, is called the "coercive force", H_c and will of course vary with the material and with B_{max} . The value of the coercive force after previous magnetization up to saturation point is the 'coercivity' of the iron. If the "cycle of magnetization" is completed by first reducing H to zero and then increasing it in the opposite direction to produce $+B_{max}$ again, the curve follows the line FHIA. The loop so formed is called the "hysteresis loop"[3].

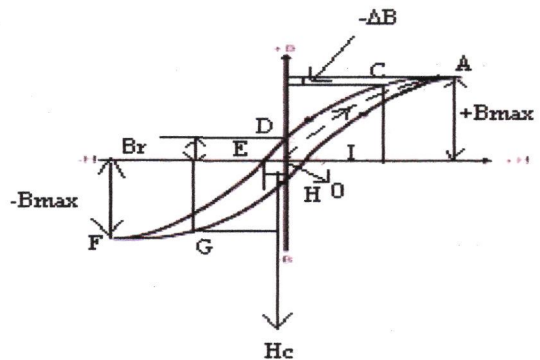


Figure 6: Hysteresis loop

2. OBJECTIVE

The project is to design the suitable switching of the circuit for testing performance of the secondary side at core transformer as shown in Figure 3. By designing the switching circuit with IGBTs as a switch, it is consider the process in order to get the B-H curve was very fast. As example, by measuring the area of the hysteresis loop in Figure 7, the hysteresis loss for the core may be obtained.

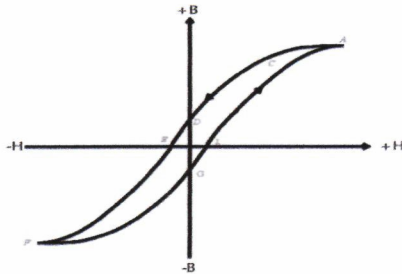


Figure 7: B-H curve

3. SCOPE OF WORK

The scope of work of this project is to construct the switching circuit for testing the performance core of transformer at the secondary side using MATLAB and PSIM simulations and the IGBTs as a switch. From testing and simulate the switching circuit, the results can be consider used to measure the performance of the core transformer.

4. METHODOLOGY

The switching circuit in Figure 1 used by Mohd Yassir[6] in order to investigate the performance of the core at the electronic transformer. From that, the switch RS1 was used in order to complete the hysteresis loop for measure the performance of the core of transformer. In order to operate the switch RS1 as a fast switching, the IGBTs were used replace the manual switch. Then, the circuit of switch RS1 was constructed on the breadboard and tests the switching circuit. Hence, analyze the result of simulation switching and the hardware switching results. The general flow chart of this methodology is shown in Figure 8.

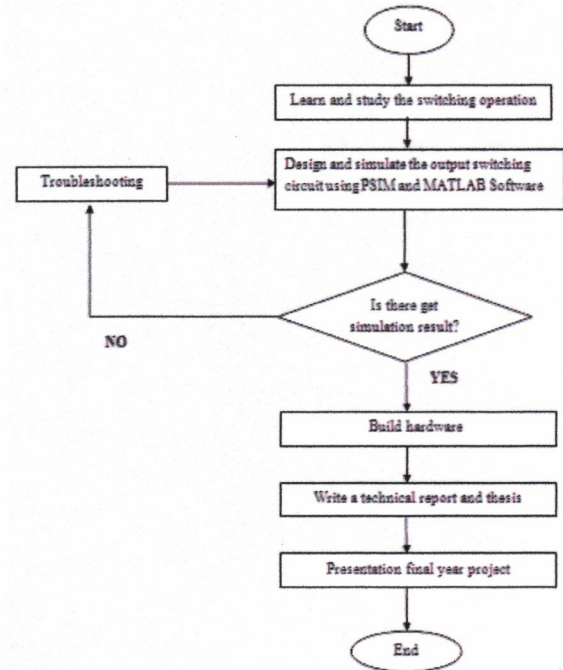


Figure 8: Methodology

5. SIMULATE THE SWITCHING CIRCUIT

In this part, the purposed of the PSIM and MATLAB software are to show the switching operation that are used in circuit design in order to test the performance of core transformer at the secondary part. By using the MATLAB and PSIM software the circuits can be simulating in order to get the results.

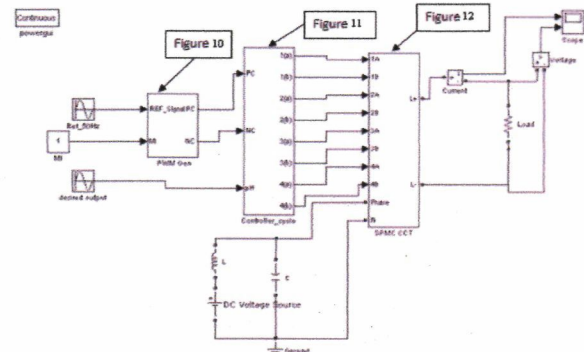


Figure 9: The switching circuit arrangement in the secondary side of core transformer in MATLAB simulation

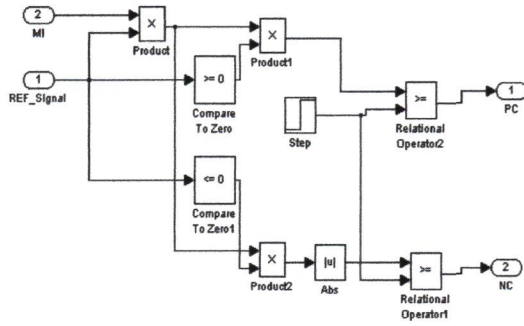


Figure 10: The PWM circuit

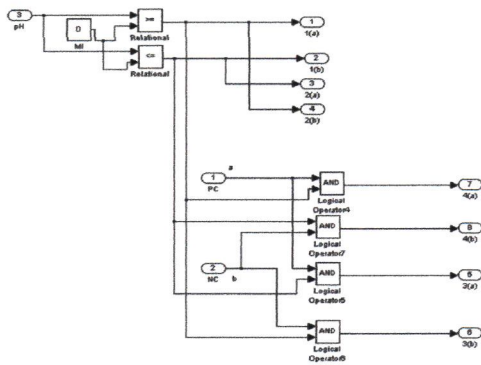


Figure 11: The controller circuit

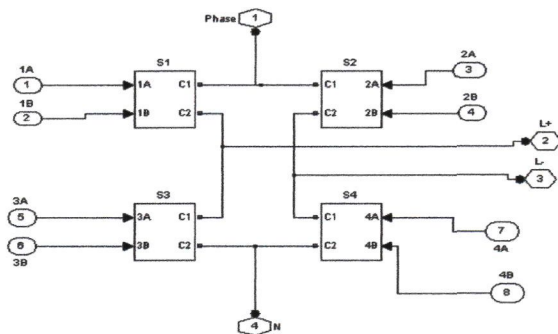


Figure 12: The SPMC circuit

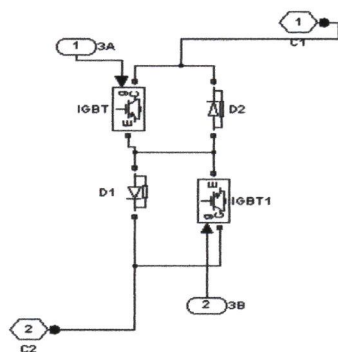


Figure 13: The bi-directional switch

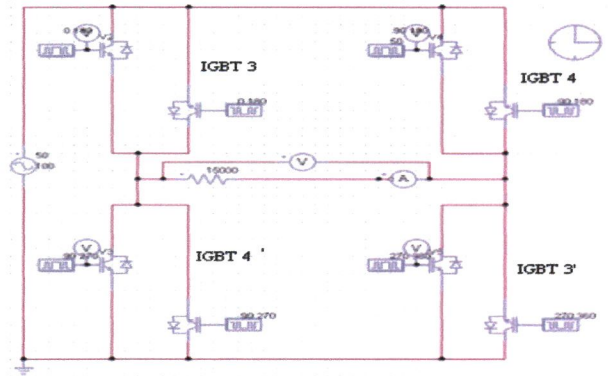


Figure 14: Circuit for switch on and switch off in SPMC pattern

The circuit shown in Figure 9 was used for the switching in the secondary side of core transformer in MATLAB simulation which it used to test the core transformer. The driver circuits were designed to generate the SPWM patterns that are used to control the power switches, which comprising 8 IGBTs in the SPMC circuit. For the circuit in Figure 14, it is very simple circuit and produces the best result to produce B-H curve when the circuit simulated by PSIM software. It contains 8 IGBTs for the switching in SPMC pattern. The frequency for IGBTs and supplier AC from the core transformer are maintained for 50Hz. For the IGBT 3 and IGBT 3', the cycles 0° degree until 180° degree and the 270° degree until 360° degree were setup. Then, for the IGBT 4 and IGBT 4', the cycles 90° degree until 180° degree and the 90° degree until 270° degree were setup.

6. PROCEDURE FOR TESTING

In the project, the IGBTs were introduced in the RS1 circuit as a switch which it can switch in very fast compare with the manual switch RS1 in order to test the performance of the core at the secondary side of the core transformer. From the previous work done by Yassir[6], the area of B-H curve can be adjusted by resistance R3 to increase or decrease performance the core of transformer. The value of H_{max} required to produce the value of B_{max} to be used during the test is obtained from the previously determined B-H curve of the specimen. The resistances R2 and R4 are then adjusted so that the magnetizing current is such that this value of H is obtained when switch S2 is in "off" position. Resistance R3 is adjusted to such a value that a suitable reduction of the current in the magnetizing winding is obtained when this resistance is switched in circuit. Resistance R1 is adjusted so that a convenient deflection of the galvanometer is obtained when the maximum value of the magnetizing current is reversed. The resistances R1,

R2, R3 and R4 showed in the Figure 1. In order to test the performance of the core some steps must be followed. It was explained from the summary in the Table 1 for the procedures in testing the core of transformer in order to get the B-H curve.

1. Switch RS2 is then places on contacts 11' and the short circuiting key K opened.
2. The next step is to throw switch S2 quickly over from the "off" position to contact b, thus shunting the magnetizing winding by R3.
3. The key K is now closed, and switch RS2 reversed on the contacts 22'. Switch S2 is then opened and RS2 moved back again to contacts 11'.
4. When K closed and S2 in the "off" position, place RS2 on contacts 11' in order to obtain section DEF. Then place S2 on contact a, open the key K, and rapidly reverse RS2 on to contacts 22'. To bring the magnetization of the specimen back to point A, close key K, open S2 and reverse RS2 on to contacts 11'.
5. By continuing this process, other points on the section DEF of the loop are obtained.
6. The processes were continuing until the loop of the B-H curve was completed to measure the performance of the core from the point F until back to point A.

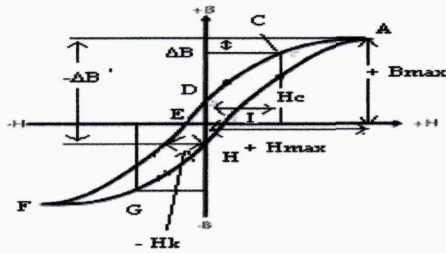


Figure 15: Hysteresis loop

Table 1: Summary of the sequence of steps

STEP	RS1	RS2	S2	K	REFERENCE
1	33'	11'	off	open	Point A
2	33'	11'	b	open	Point C
3	33'	11'	b	close	Back to point A and continue to point AD
4	33'	22'	b	close	
5	33'	22'	off	close	Point DEF
6	33'	11'	off	close	
7	33'	11'	a	close	
8	33'	11'	a	open	Point F
9	33'	22'	a	open	
10	44'	11'	off	open	
11	44'	11'	b	open	Point G
12	44'	11'	b	close	Back to point F and continue to point FH
13	44'	22'	b	close	
14	44'	22'	off	close	
15	44'	11'	off	close	

16	44'	11'	a	close	Point HIA
17	44'	11'	a	open	
18	44'	22'	a	open	

The switches S2 and RS2 also showed in the Figure 1. From the summary in the Table 1, the function of the RS1 is to complete the loop of the B-H curve. From the project, the time of the switch RS1 is operated depend on the operation of the switch RS2 and switch S2 in the primary part. The switch RS1 is changing it operation only twice in order to complete the hysteresis loop. Firstly, the switch RS1 is function when the IGBT 3 and IGBT 3' are on condition at the step 1 until the step 9. Then, the current will flow through the switch K and Ballistic Galvanometer. From the result, it will produce the curve of the B-H curve from the point A until point F. Secondly, the switch RS1 is function when the IGBT 4 and IGBT 4' are on condition at the step 10 until the step 18. Then, the current will flow through the switch K and Ballistic Galvanometer. From that it will complete the loop of the B-H curve from point F until back to point A. It was note that, the switch K function followed the operation circuit at the primary part by opening and closing the switch K. Besides that, the operation in the switch RS1 is changed from IGBT 3 and IGBT 3' on condition to IGBT 4 and IGBT 4' on condition when the switches S2, RS2 and K were off, IGBT 1 and IGBT 1' are on condition and open. It showed in the Table 2 for the operation in the switch RS1.

Table 2: The operation of the switch RS1

STEP	RS1	RS2	S2	K
1	33'	11'	off	open
10	44'	11'	off	open

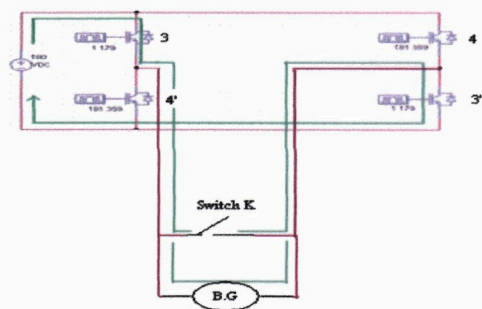


Figure 16: The switching operation using IGBTs when the switch IGBT 3 and IGBT 3' is ON in the RS1 circuit

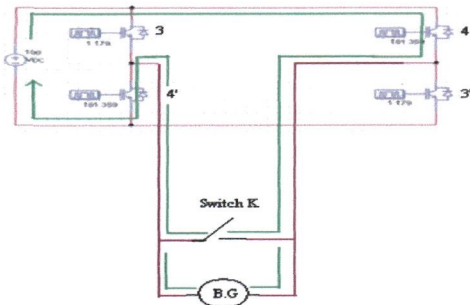


Figure 17: The switching operation using IGBTs when the switch IGBT 4 and IGBT 4' is ON in the RS1 circuit

For the switching function purpose, certain rules of switching observed from the Figure 16 and Figure 17.

1. At any certain time 't', only two IGBTs, IGBT 3 and IGBT 3' will be in 'ON' and conduct the current into the IGBT 3 then it will pass through switch K and Ballistic Galvanometer (B.G) and lastly it will flow through the IGBT 3'. The IGBT 4 and IGBT 4' will be 'OFF' and the current did not flow through it.
2. At any certain time 't', only two IGBTs, IGBT 4 and IGBT 4' will be in 'ON' and conduct the current into the IGBT 4 then it will pass through switch K and Ballistic Galvanometer (B.G) and lastly it will flow through the IGBT 4'. The IGBT 3 and IGBT 3' will be 'OFF' and the current did not flow through it.

7. DESIGN AND HARDWARE IMPLEMENTATION

For the hardware implementation in driver switching, there are five main components needed for the gate drive. The gate drive is to control the IGBT and the components are Integrated Circuit (IC555) with PWM, Inverter SN7400, Opto-Coupler, Modified IR2110 and IGBT.

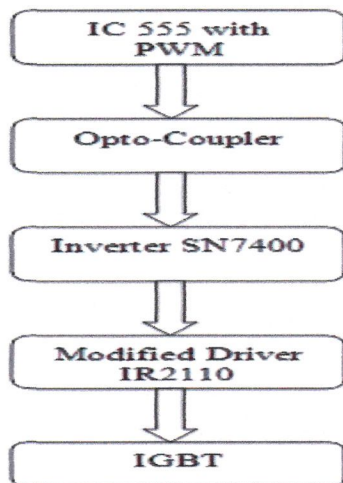


Figure 18: The Flow Chart for the Gate Drive

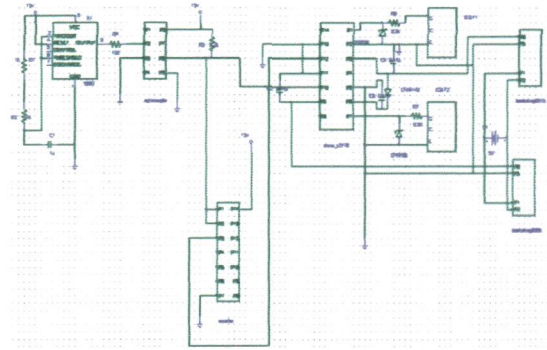


Figure 19: The circuit diagram of driver circuit block

This project employs IC 555 to generate PWM, Opto-Coupler to provide the isolation drive signal, the modified IR2110 as a driver.

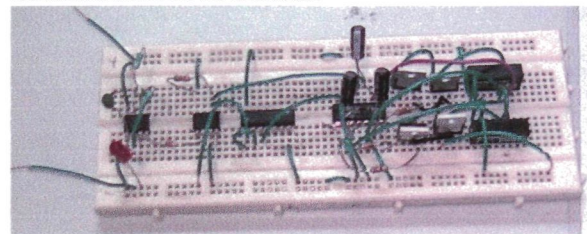


Figure 20: The hardware switching circuit

Switching

The main part in the implementation of this project is to drive four IGBTs as a switching element. The gate drive requirements for a power MOSFET or IGBT, utilized a high-side switch driven in full enhancement. In other means, the drain is connected to the high voltage rail.

Therefore, the lowest voltage drop across its terminals can be summarized as follows:

1. The gate voltage must be 10 V to 15 V higher than the drain voltage. In order to be in a high-side switch such gate voltage would have to be higher than the rail voltage which is frequently the highest voltage available in the system.
2. The gate voltage must be controllable from the logic which is normally referenced to ground. Thus, the control signals have to be level-shifted to the source of the high side power device which in most applications swings between the two rails.

The driver IR2110 was chosen in order to drive the IGBT. International Rectifier's family of MOS-gate drivers (MGDs) integrate most of the functions required to drive one high-side and one low-side power MOSFET or IGBT in a compact and high performance package. With the addition of few

components, they provide very fast switching speeds and low power dissipation.

The proprietary HVIC (High Voltage IC) and latch immune CMOS technologies enable monolithic construction. The logic inputs are compatible with standard CMOS or LSTTL outputs, so that the output drivers feature a high pulse current buffer stage designed for minimum driver cross-conduction. Furthermore, the propagation delays are matched to simplify use in high frequency applications [4]. Lastly, the floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration which operates up to 500 volts.

IGBT gate drive requirements

The IR2110 is a high voltage, high speed half-bridge driver for driving n-channel MOSFET or IGBT gated power devices [1]. The blocking voltage of this driver is 500V DC which provides the capability for application on most rectified 230V AC line.

Integrated Circuit (IC555) with PWM

This circuit IC555 is purpose to generate the input signal of inverter SN7400 with PWM waveform, since the circuit of IC555 required the input voltage is 5V. Pulse width modulation (PWM) is the process of switching the power to a device on and off at a given frequency, with varying on and off times. These on and off times are referred to as duty cycle. The diagram in Figure 21 shows the waveforms of 10%, 50%, and 90% duty cycle signals.

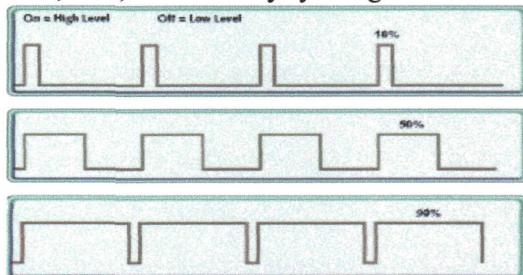


Figure 21: Pulse generation with controllable width (mark space ratio)

From the diagram in Figure 21, a 10% duty cycle signal is ON for 10% of the wavelength and OFF for 90% while a 90% duty cycle signal is ON for 90% and OFF 10%. These signals are sent to the modified driver IR2110 at a high enough frequency to turn on IGBT. The end result of the PWM process is that overall power which is sent to the modified driver IR2110 can be adjusted from OFF (0% duty cycle) to full ON (100% duty cycle) with good efficiency and stable condition[5]. The IC 555 in the PWM circuit is

configured as an astable oscillator. This means that once power is applied, the IC555 will oscillate without any external trigger.

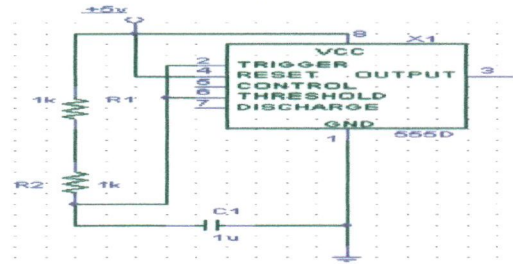


Figure 22: IC timer as switching controller

In this project, since the switching sequence is known, therefore the ON time, OFF time and duty cycles for the PWM need to be calculated. The formula is as stated below.

Choosing R1, R2 and C1:

R1 and R2 should be in the range $1k\Omega$ to $1M\Omega$. It is best to choose C first because the capacitors are available in just a few values. So, the capacitor's value $47nF$ was used in order to get the best value of frequency. The paragraph below shows the some calculations did in order to get the best value of frequency.

$$\text{To calculate frequency} = \frac{1}{0.693 \times (R_1 + (2 \times R_2)) \times C_1}$$

$$R_1 = 1K\Omega$$

$$R_2 = 1K\Omega$$

$$C_1 = 47nF$$

$$\text{Frequency} = \frac{1}{0.693 \times [1K + (2 \times 1K)] \times 47nF}$$

$$= 10.23 \text{ KHz}$$

To calculate on time,

$$T_{\text{sec on}} = 0.693 \times (R_1 + R_2) \times C_1$$

$$T_{\text{sec on}} = 0.693 \times (1K + 1K) \times 47nF = 65.142\mu s$$

To calculate off time,

$$T_{\text{sec off}} = 0.693 \times R_2 \times C_1$$

$$T_{\text{sec off}} = 0.693 \times 1K \times 47nF = 32.6\mu s$$

$$\text{Duty cycle} = \frac{R_2 \times 100\%}{R_1 + (2 \times R_2)}$$

$$\begin{aligned} \text{Duty cycle} &= \frac{1K}{1K + (2 \times 1K)} \\ &= 33\% \end{aligned}$$

So, from the calculation the resistors values $1K\Omega$ for both resistors used in the project in order to get the desired output times.

Opto-Coupler

In this project, an Opto-Coupler was used as a new method of isolation signal drive for isolations which previously employed i.e the use of a pulse transformer [4]. Opto-Coupler used in this project is 6N136 which is single signal opto-coupler. The Opto-Coupler device provides an isolation that fulfils that requirement which it built up with inverter but the switching is slow [5]. Each signal has been connected to its own input of Opto-Coupler.

Inverter SN7400

The function of the device is to invert the input signal [4]. Note that the output of Opto-Coupler is inversion signal from its input.

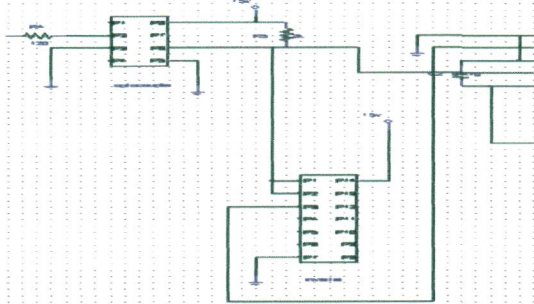


Figure 23: The connection between the Opto-Coupler and inverter

Modified IR2110

This is the driver that can trigger the gate of IGBT which produce voltage in the range of 12V to 22V [4]. Since the driver is capable to drive two gates of IGBTs, port 1 and port 7 were utilized. According to the data sheet of IR2110, port 1 is a low side gate drive output and port 7 is a high side gate drive output.

The ground connection for this driver should be connected separately from the ground connection of Opto-Coupler and inverter SN7400. This is for the isolation of the drive signal [5].

The port 10 and 12 is the input signal. The output from Opto-Coupler which is already an isolated signal enters the port 10 of the driver IR2110.

A single $3.2k\Omega$ resistor is used to control the Turn ON and Turn OFF of the IGBT from the driver as shown in Figure 24. Besides that, the resistor is also to minimize the current flow to the gate. This will ensure that the IGBT is in voltage driven condition.

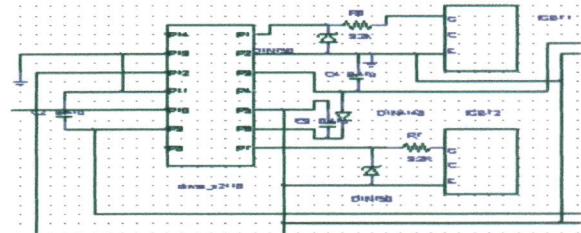


Figure 24: The circuit diagram of modified IR2110 gate drive

Isolated 1W dual output DC/DC converters

By referring to driver IR2110 in Figure 24, the driver needs two supplies which are 5V and 15V. To have an isolate power supply, the new devices such as isolated 1W dual output DC/DC converter were introduced [4]. By utilizing this, it can reduce the consumption of power supply. By supplying only 5V, this device can produce 5V and 15V separately which needed for the driver IR2110. Figure 25 shows the connection of isolated 1W dual output DC/DC converters to the modified IR2110 [5].

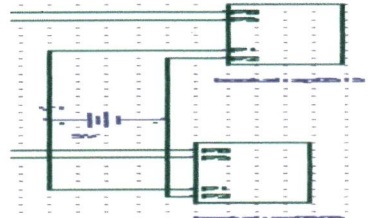


Figure 25: The isolated 1W dual output DC/DC converters

8. RESULTS AND DISCUSSION

The purpose of the project is to design the switching circuit at the secondary part. The switch is operating only twice to complete the B-H curve. The MATLAB and PSIM simulations also did in order to test the switching circuit. The IGBTs were used due to its high switching capabilities and high current carrying capacities desirable for high-power applications. In the project, some procedures must be followed and understand for getting the best result, especially when constructing the switching circuit in PSIM and MATLAB simulations and hardware implementation.

Table 3: The maximum value of voltage from the PSIM simulation

Time	0.00490818
VP1	16.6597
Time	0.015025
VP1	-16.6661
Time	0.0249416
VP1	16.6638

Table 4: The maximum value of current from the PSIM simulation

Time	0.005
I1	0.00111111
Time	0.01501
I1	-0.00111111
Time	0.0249416
I1	0.00111092

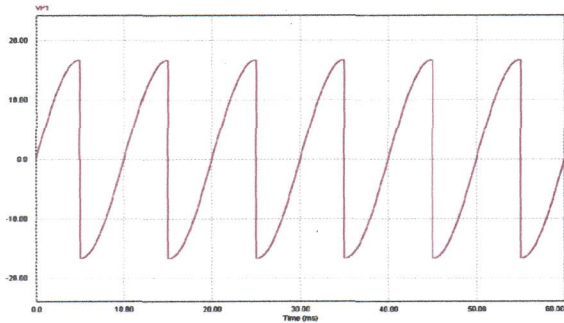


Figure 26: Simulation result from the load voltage in PSIM Simulation

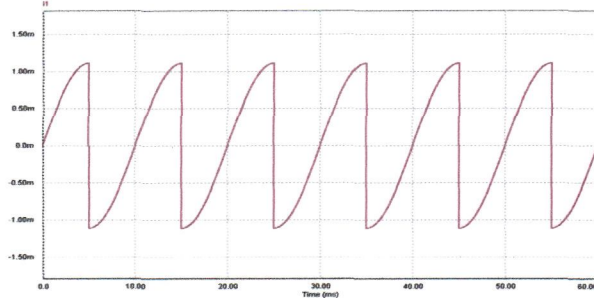


Figure 27: Simulation result from the load current in PSIM simulation

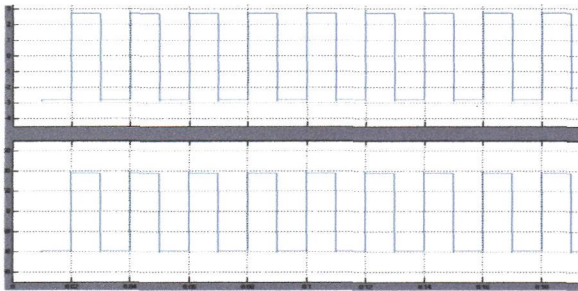


Figure 28: Simulation result from the load voltage and current

From the simulation part, PSIM software is advantage than MATLAB software because it gives the better results of simulation. From the Figure 27, the hysteresis loop can be plotting in order to show the performance of the core. It showed when the current applied in the magnetizing winding is increased from zero to 1.11mA and the voltage is 16.66V. Then, it will be found that it shape is as shown by the portion A at the time 5ms. After that, the current is reduced gradually to zero again, after some flux density B_{max} has been attained, the curve for descending values of H takes the form AD at the time 10 milliseconds. If the direction of the magnetizing current is now reversed, and gradually increased in this reverse direction until a flux density $-B_{max}$ is again obtained, the curve follows the line DEF. So the curve from point A until point F got from the simulation at the time 15 milliseconds. At

that time, the values current and voltage are -1.11 mA and -16.66V. After that, the “cycle of magnetization” is completed by first reducing H to zero and then increasing it in the opposite direction to produce $+B_{max}$ again, the curve follows the line FHIA. So, the curve from the point F until point A got from the simulation at the time 25 milliseconds. At that time, the values of current and voltage are the same as the values at the point A which the values current and voltage are 1.11mA and 16.66V.

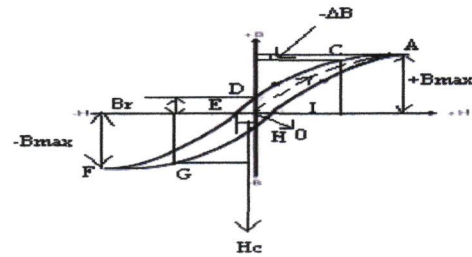


Figure 29: Hysteresis loop

From that, at the time 5 milliseconds the IGBT 3 and IGBT 3' are on condition, the point A was produced. After that, at the time 15 milliseconds the IGBT 4 and IGBT 4' are on condition which it produced point A until point F. Then, at the time 25 milliseconds the IGBT 3 and IGBT 3' are on condition. Then, the point F until point A was produced to complete the hysteresis loop.

From the hardware results in Figure 30 until Figure 34, the explanation have briefly describe in the hardware implementation part.

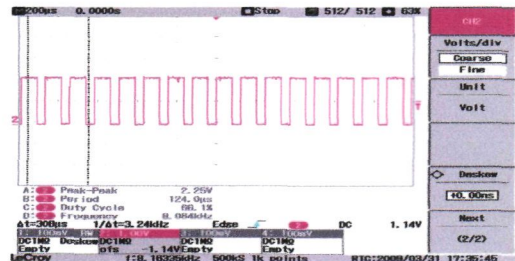


Figure 30: IC Timer waveform



Figure 31: Opto-Coupler waveform

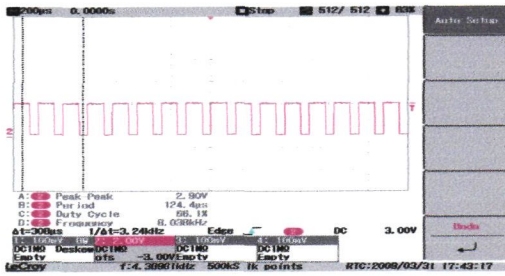


Figure 32: Inverter waveform

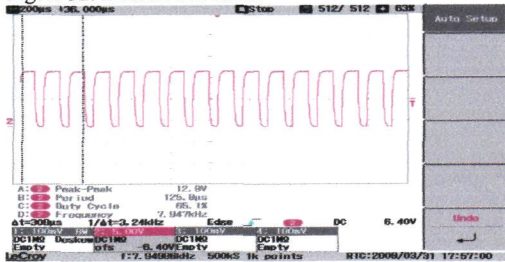


Figure 33: IGBT waveform



Figure 34: Driver IR2110 waveform

9. CONCLUSION

By using the IGBTs as switching circuit the job to switch on and switch off become very easy and fast. From the PSIM simulation, it is considered when the IGBT 3 and IGBT 3' on condition, the curve A will produce and when the IGBT 4 and IGBT 4' on condition, the curve from point A until point F will produce. After that, the IGBT 3 and IGBT 3' on condition to produce the curve back from the point F to point A. So the complete of the B-H curve will get to measure the performance of the core transformer from the PSIM simulation. For the MATLAB simulation and hardware implementation, the results were unsuitable for getting the B-H curve. It is maybe the values of parameters used in the simulation and the components in the hardware implementation were improper values. From the simulation in PSIM software, the conclusion can be made that for the first 5 milliseconds the IGBT 3 and IGBT 3' are on. Then for the next 10 milliseconds the IGBT 4 and IGBT 4' are on and the last 5 milliseconds of each cycle 5 milliseconds it continued to the next cycle for another 5 milliseconds back to IGBT 3 and IGBT 3' are on.

10. FUTURE DEVELOPMENT

The switching circuit has ability to switch on and off in very fast by using IGBT devices [1]. Before this, the manual switch K used during the project was difficult to turn and late to operate the circuit [6]. Hence, the switching circuits with the IGBTs is suggest to implement at the future which it conducted by the IC timer at the switch K. Besides, in the future hope that the switch RS1 is able to operate with the core transformer for testing the performance of the core of electronic transformer at the secondary part in order to produce the complete of B-H curve.

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12. REFERENCE

- [1] M.H.Rashid, "Power Electronics- Circuits, Devices and Applications", Pearson Education, Inc.3rd Edition, 2004.
- [2] Nathan R. Grossner,"Core Materials", *Transformer for Electronic Circuit*, pp. 114-115, 1967.
- [3] E.W Golding & F.C Widdis, "Magnetic Measurements", *Electrical Measurements And Measuring Instruments*, pp 371-432, 5th edition, December 1962.
- [4] Mohd Faizal Bin Othman, *Gate Drive Study for Multiple Switches*, thesis for Bachelor of Engineering (Hons) Electrical, UiTM, May 2008.
- [5] Mohd Hafiz Bin Ahmad, *Improvement On The Safe Commutation Technique for SPMC On The Primary Side Converter of Electronic Transformer*, thesis for Bachelor of Engineering (Hons) Electrical, UiTM, November 2008.
- [6] Mohd Yassir Bin Ali, *Design Of A Circuit for Testing The Performance of The Core of Electronic Transformer*, thesis for Bachelor of Engineering (Hons) Electrical, UiTM, November 2008.
- [7] Norazmi Bin Arifin, *Improved Switching Technique for A New Single Phase Cycloconverter Single Phase Matrix Converter (SPMC)*, thesis for Bachelor of Engineering (Hons) Electrical, UiTM, November 2008.