Analysis and Design of Half Bridge DC/DC Series Parallel Loaded Resonant Converter for Undergraduate Teaching Laboratory (UTL)

Wan Adli Muzani Bin Wan Mohamed
Faculty of Electrical Engineering
Universiti Teknologi MARA Malaysia
40450 Shah Alam, Selangor, Malaysia
e-mail:deli_binja@yahoo.com

Abstract—**This paper proposed to design the DC power supply using half bridge LCC series parallel loaded resonant converter (HBSPRC) application for undergraduate teaching laboratory. The DC power supply input voltage is 20 to 12V and DC output voltage is maintained at 10V. The converter is design based on output power 2.0W and the starting switching frequency,fs is 50kHz. The operation above resonance is preferred, because the power switches turn on at zero current and zero voltage. The experiment result should be compared between theoretical and computer simulation based on the application and desired output power. The Operating theory and equation are also developed. Theoretical, simulations and experiments are come out to complete the analysis and design of study.**

Keywords-Half-Bridge, Zero Voltage Switching, MOSFET, Resonant Converter, DC/DC Converter and output power,2.0W.

I. INTRODUCTION

The Series–Parallel Resonant Converter (SPRC), are combined both of series (SRC) and parallel (PRC). SPRC also given their advantages these are good cross regulation characteristic, short circuit protection capability, and good efficiency at light loads. Therefore, SPRC exhibits superior performances characteristics over both SRC and PRC [1]. Series -parallel resonant converters are based on topologies with 3 reactive elements such as the topologies of LCC resonant converters. If compared with SPRC, the higher order resonant tank of converters will show higher performance, higher efficiencies and higher power densities.

Hence, while the operation of the input voltage, the power supply should be deliver the regulated power at the required voltage and current.

II. CIRCUIT DESCRIPTION OF SPRC

a. A Circuit Description

The series-parallel converter combines the advantages of the series and parallel converters an accordingly the series-parallel dc/dc converter is install between the dc input source to control the operating points of the dc source. This section describes the circuit topology and the operation principle of the proposed the half bridge series-parallel resonant converter (HBSPRC) for application undergraduate teaching laboratory using buck chopper experiments.

Several efforts have recently been made in the modeling and analysis of the resonant converter and combines with the buck chopper experiment as shown in figure 1.The inverter employs the half bridges rectifier, or controlled a pair of switches S1 and S2 by using driver MOSFET(IRS2153). This driver is chosen because of its fast switching and high frequency up to 500 kHz. Then to obtain the switching frequency 50 kHz, the suitable driver MOSFET its self-Oscillating Half Bridge Driver IC (IRS2153). The characteristic of IRS2153 is consisting of Variable Resistor 3kΩ and Capacitor 2.2nF [11].

Capacitor, Cs is connected in series with inductor Ls as in the series resonant inverter, and the half bridge rectifier is connected in parallel with capacitor Cp as in the parallel resonant converter. While each of the bidirectional power switch comprises a MOSFET and its body diode.

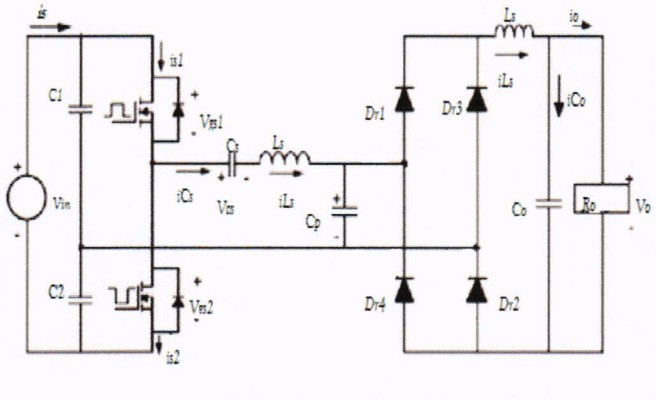

Figure 1. Basic schematic LCC Half Bridge SPRC

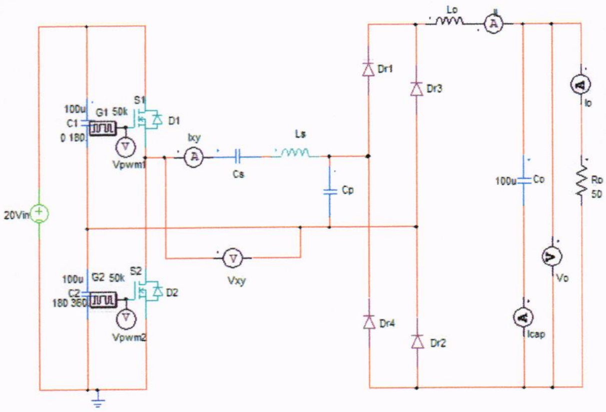

Figure 2. Schematic Diagram by PSim.

To facilitate the analysis, that the active power switches can be represented by a pair of bidirectional switches operated at a 50% duty ratio over a switching period *T.* For the half bridge topology, each switch has an active power switch an antiparallel diode.

These two active power switches are driven by overlapping rectangular-wave trigger signals *VGS*1 and *VGS*2 with dead time 1.1 us base on data sheet. Thus, the effect of the power switches through an equivalent square wave voltage source with amplitude equal to ±*Vs/2*.

The dc voltage can be varied and closely regulated by controlling the switching frequency. Consequently, the current input to the bridge rectifier has constant amplitudes +*Io* and –*Io*, depending on whether the voltage $V_{CP}(t)$ is positive or negative, respectively. The frequency of this current waveform is the same as the switching frequency [2].

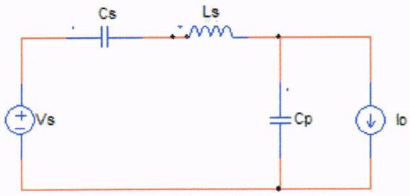

Figure 3. Simplified equivalent circuit of HBSPRC

b. A Circuit Operation Principles

Figure 3 shows these observations; HBSPRC can be modeled as resonant circuit and square wave current source ± *Io* in parallel of the resonant capacitor. Then the equivalent circuit of the HBSPRC can be simplified.

III. STEADY STATE ANALYSIS

A. Basic Equation of Resonant Converter

The current flow due to each voltage component is obtained using the circuit impedance at the appropriate frequency. Meanwhile the total current may be determined by superposition.

In the half-bridge, the characteristic impedance of the L-C-R, Z_{LCR} at frequency ω is

$$Z_{LCR} = Z\left[\frac{1}{Q} + j\left[\frac{\omega_S}{\omega_O} - \frac{\omega_O}{\omega_S}\right]\right] \tag{1}$$

Where ω_s = Switching frequency
$= 2\pi f_S$
ω_o = Resonant frequency
$= 2\pi f_O$

and the relation for Normalized Switching Frequency, ω_n is

$$\omega_n = \frac{\omega_s}{\omega_o} \tag{2}$$

And the characteristic impedance Z_o of the bridge load is given by

$$Z_O = \sqrt{\frac{Lr}{Cr}} \tag{3}$$

Where Lr = Resonant Inductor
= Ls, series Inductor
Cr = Resonant Capacitor
= Cs, series Capacitor

Then

$$\omega_O = \frac{1}{\sqrt{(L_s C_s)}} \tag{4}$$

$$Q = \frac{\omega_O L_S}{R} \tag{5}$$

Therefore, the resonant tank network can get

$$L_S = \frac{QR}{\omega_O} \tag{6}$$

$$C_S = \frac{1}{L_S(\omega_O{}^2)} \tag{7}$$

In designing a converter, $C_p = C_s$ is chosen which is

$$\frac{C_P}{C_S} = 1 \tag{8}$$

switching frequency, $\omega_S = 2\pi f_s$ and Quality factor, Q = 0.5 are used as parameters to find the voltage ratio conversion, M.

That,

$$M = \frac{V_O}{V_{in}}, \text{ voltage gain} \tag{9}$$

Where V_O is output dc voltage and V_{in} is supply dc voltage or Vs. Thus the voltage conversion ratio for HBSPRC of the circuit in Figure 1 can be expressed as Eq. (10) is

$$\frac{V_O}{V_{in}} = \frac{\frac{1}{2}}{\left[\frac{\pi^2}{8}\left[1+\frac{C_P}{C_S}\left(1-\left[\frac{\omega_S}{\omega_O}\right]^2\right)+jQ\left[\frac{\omega_S}{\omega_O}-\frac{\omega_O}{\omega_S}\right]\right]\right]} \quad (10)$$

B. *Assumptions*

Follow the procedure for application of the experiment laboratory must to design for several part and system. These parts are

i) DC Source (20 – 12)V, supply voltage
ii) Resonant Circuit (Main Circuit – resonant tank, *Cs*, *Ls*, and *Cp*)
iii) Output Rectifier and Filter (Main Circuit- the output full bridge and low pass filter, *Lo* and *Co*)
iv) Voltage control Oscillator, VCO (Driven Circuit)
v) Switching frequency control (Driven Circuit)
vi) Load (maintained the output voltage, 10V)

The Quality Factor, Q is 0.5, starting switching frequency, fs is *50KHz*, starting supply voltage, Vin is 20V and then refer to the graph quality factor, Q = 0.5 which show in Figure 4, where

i) Normalized switching frequency ,

$$\omega_n = \frac{\omega_S}{\omega_O} \quad (11)$$

ii) Ratio of C_P and C_S ,

$$\frac{C_P}{C_S} = 1.0 \quad \text{from(8)}$$

iii) Voltage conversion ratio,

$$\mathrm{M} = \frac{V_O}{V_{in}} \quad \text{from(9)}$$

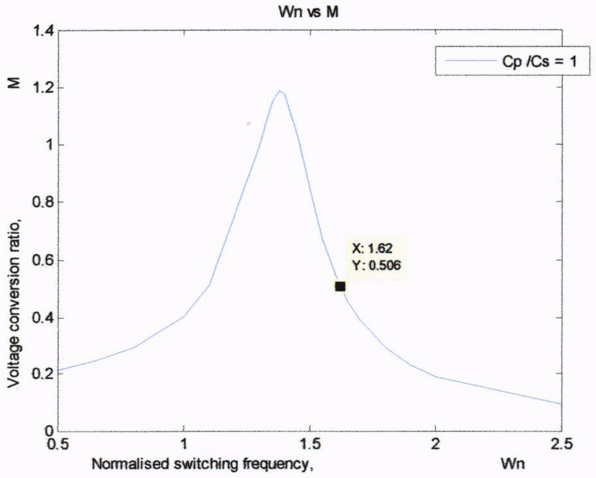

Figure 4. Q = 0.5 and Cp/Cs = 1.0 for LCC of HBSPRC

C. *Assuming and Design of output filter components.*

The Low pass filter components are inductor, *Lo* and capacitor, *Co* are shown in Figure 1. It's used for purposed to attenuate the low frequency ripple in the output voltage which results from the pulsating nature of the power absorbed dc mains.

The assuming that all low frequency components flow through the capacitor and then the dc components flow through the load. For this study and simulation both of the output filter components that output inductor and output capacitor are 5mH and 100mF respectively. While the dc component of *Vr* must equal with output voltage, *Vo* which is resistant at the load is 50Ω. The equation of load resistant, *Ro* is

$$Ro = \frac{(Vo)^2}{Po}$$

$$= \frac{(10)^2}{2} = 50\ \Omega \quad (14)$$

The HBSPRC is comprised a dc source with an output voltage, *Vo* was maintained at 10Vdc by adjusting the converter switching frequency, *2πfs* in an open loop manner. The desired of the output power, *Po* is 2.0W. At full load of 2.0W, the switching frequency is slightly higher than the resonant frequency and the lines current closely resembles a square wave. The prototype of the HBSPRC topology is established in laboratory to verify the functional operations. These results are confirmed by computer simulation and experiment.

IV.METHODOLOGY

This section describes in detailed and follows the procedures of the flow work beginning the dc supply voltage until the results is proceed. This consists of design, calculation, computer simulation by PS IM 9 and Matlab software R2010a for apply calculation and graph of Quality factor,Q. Other than that hardware experimental design and testing also one of the part as confirm the results in order desired output that tally with equation and experiment. Then further this research in study of power electronic course that improve the buck chopper implementation, the general flow chart of this methodology is provided in Figure 5.

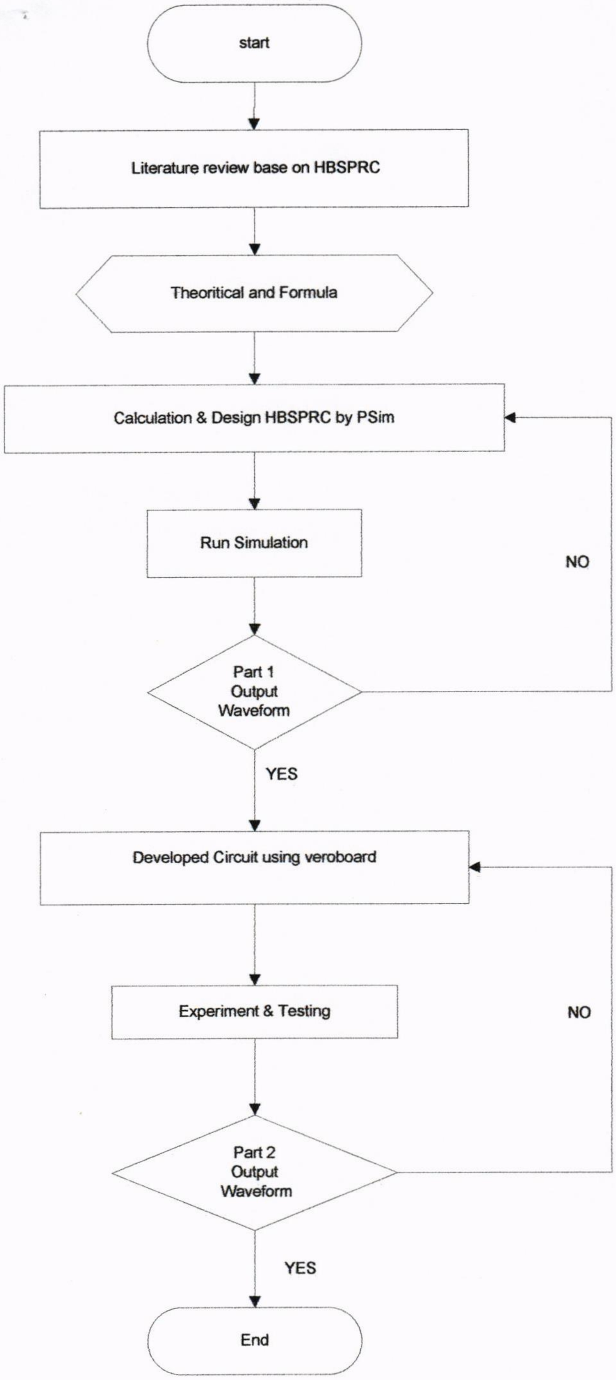

Figure 5, Flow Chart for HBSPRC application for UTL

V. RESULT AND DISCUSSION

A. Simulation Result

The parameters used for designed HBSPRC are,

i) Supply DC Voltage, Vdc = 20 -12V. Starting Vdc = 20V
ii) Power Output, Po = 2W
iii) Load Resister, Ro = 50 Ω
iv) DC Output Voltage maintain, Vo = 10V
v) Series Inductor, Ls = 0.12892mH
vi) Series and Parallel Capacitor, Cs=Cp = 0.20626uF
vii) *Starting Switching Frequency, fs = 50kHz*
viii) Quality Factor, Q = 0.5

The simulation circuit of the LCC HBSPRC is shown in Figure 6. Meanwhile the simulation results for the waveform of the LCC HBSPRC are shown in Figure 6a to 6f.

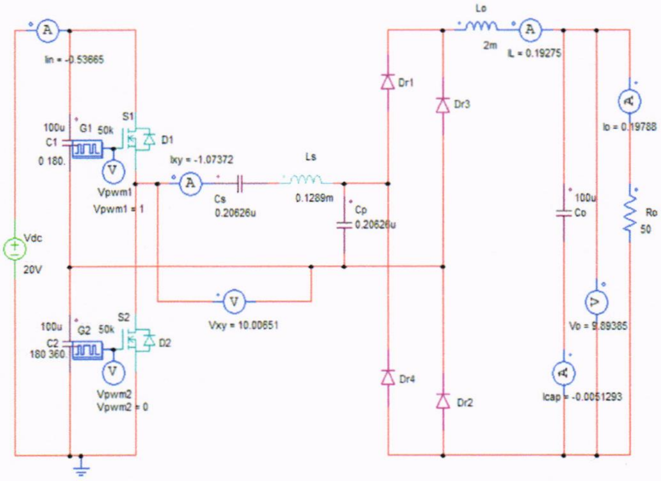

Figure 6, Simulation Circuit of the LCC HBSPRC, Vin = 10V

Simulation output waveform show Figure 6 (a – f).

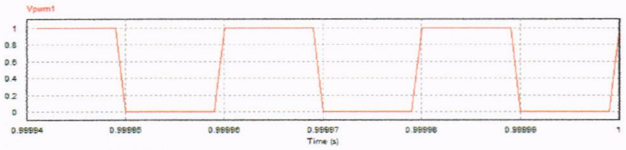

Figure 6a . Output Vpwm1

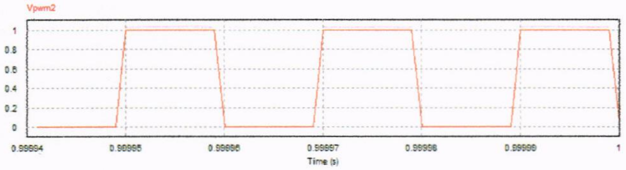

Figure 6b. Output Vpwm2

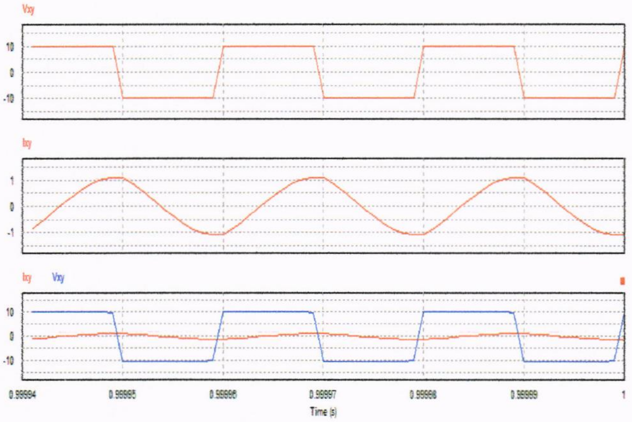

Figure 6c. Waveform of V_{xy} and I_{xy}

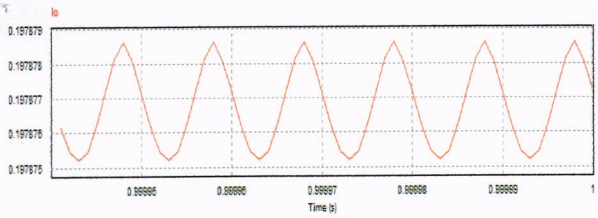

Figure 6d. Output current, I_O

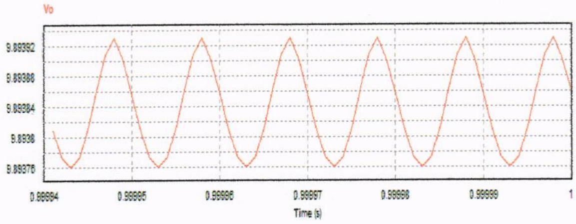

Figure 6e. Output Voltage, V_O

B. Experiment Result

The parameters used to design and develop circuit are similar with simulation design.

i) Supply DC Voltage, *Vin* = 20 -12V. Starting *Vin = 20V*
ii) Load Resister, Ro = 50 Ω
iii) DC Output Voltage maintain, Vo = 10V
iv) Series Inductor, Ls = 0.12892mH
v) Series and Parallel Capacitor, Cs=Cp = 0.20626uF
vi) Starting Switching Frequency, fs = 50kHz
vii) Quality Factor, Q = 0.5

The results from the experiment are shown in Figure 7 below, Figure 7a – 7h.

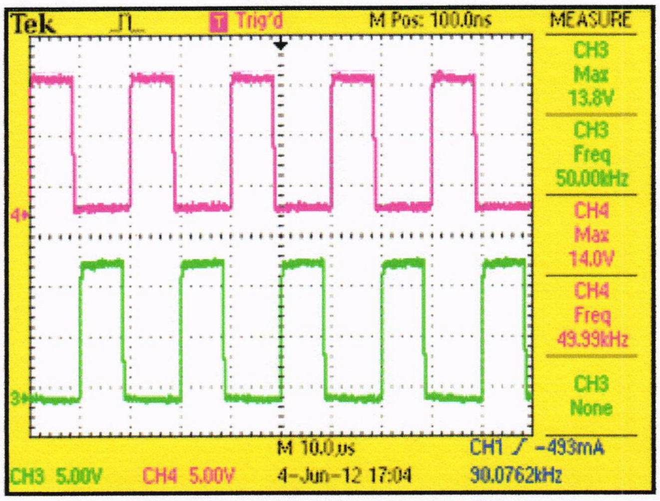

Figure 7a. Switching Vpmw1and Vpmw2

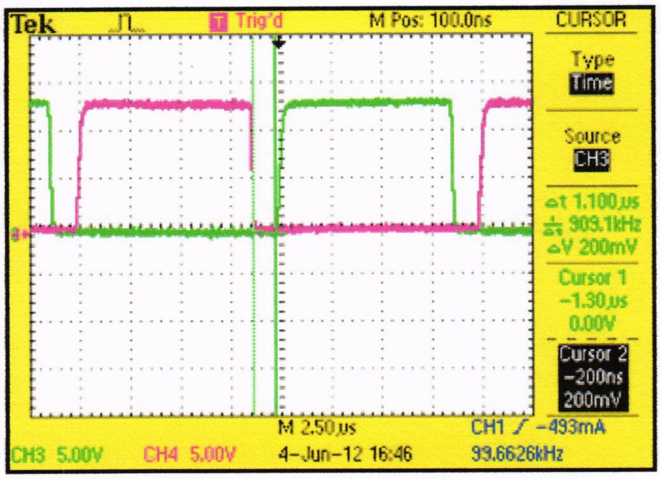

Figure 7b. The Switching, V_{GS1} and V_{GS2} and time delay , Δt

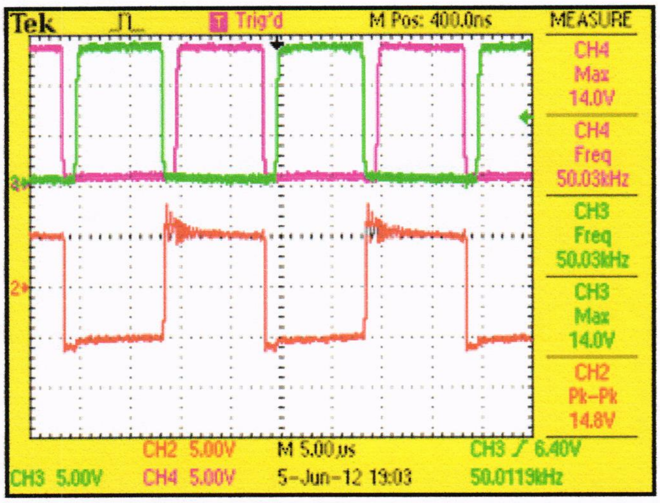

Figure 7c. Switching Vxy without Ixy

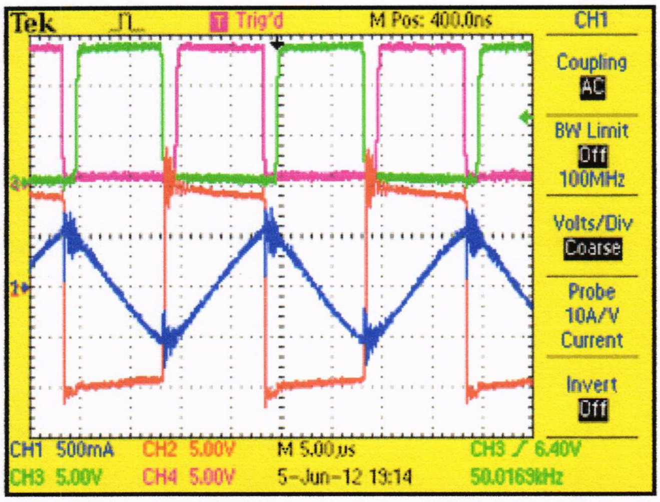

Figure 7d. Switching, Vxy and Ixy with ZVS and ZCS.

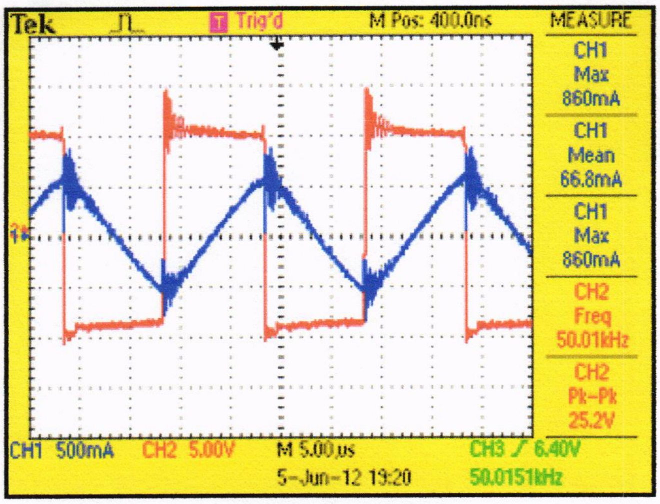

Figure 7e. ZVS

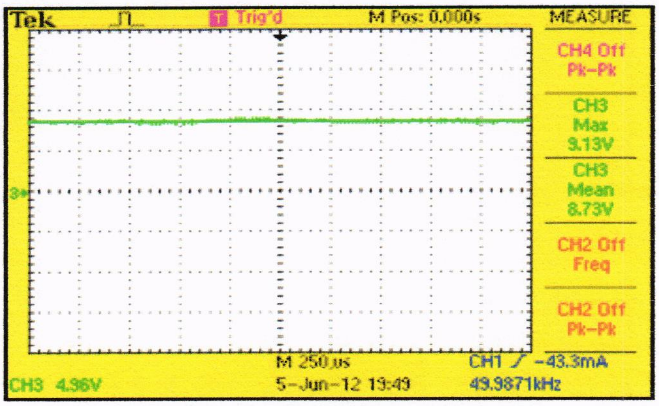

Figure 7f. DC Output Voltage, V_O

Figure 7a to 7f are output waveform from the results of the experiment.

Figure 7f shows the charging voltage waveform is a smooth dc voltage which is the ideal circuit for buck chopper. Using multimeter for Output Current and Voltage to complete this project which are shown at figure 7g and 7h below.

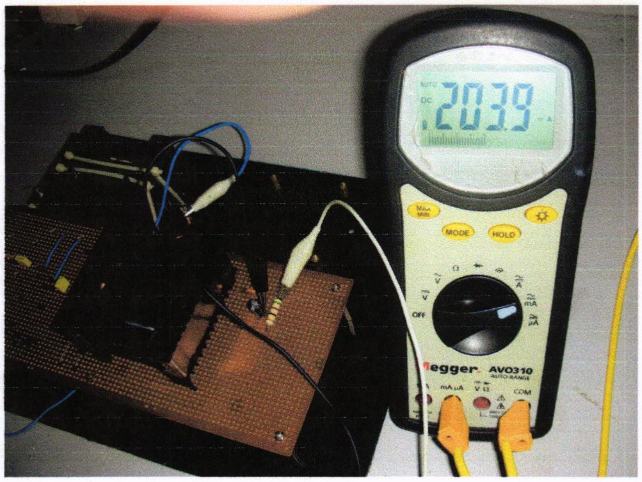

Figure 7g. Output Current, Io

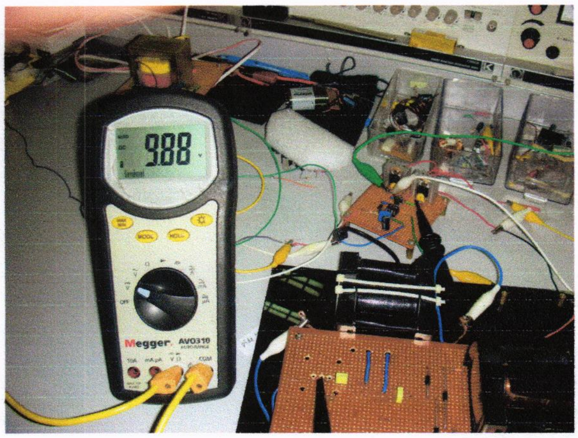

Figure 7h. Output Voltage, Vo

C. *Discussion*

The LCC HBSPRC was simulated and implemented, operation under control variable frequency vary from 45 to 50kHz. TABLE I, TABLE II and TABLE III are show the result from theoretical, computer simulation and the experiment respectively.

TABLE I. Result from Theoretical

No	Vin (V)	*fs* KHz	*fo* KHz	ω_n $\frac{fs}{fo}$	Vo (V)	Po (A)	M $\frac{Vo}{Vin}$	Q
1	20	50	30.3	1.65	10	0.5	0.50	0.5
2	18	49	30.25	1.62	10	0.5	0.56	0.5
3	16	48	30.0	1.6	10	0.5	0.63	0.5
4	14	47	30.32	1.55	10	0.5	0.71	0.5
5	12	46	30.67	1.5	10	0.5	0.83	0.5
6	10	45	31.03	1.45	10	0.5	1.00	0.5

TABLE II. Result from Simulation

No	Vin (Vdc)	f_S (kHz)	Vxy (V)	Ixy (A)	Vo (V)	Io (A)	M $\frac{V_O}{V_{in}}$
1	20	50.00	10.00	1.07	9.89	0.198	0.49
2	18	48.97	9.00	0.99	9.99	0.199	0.56
3	16	48.00	8.00	0.93	10.0	0.20	0.625
4	14	47.00	7.01	0.85	10.0	0.20	0.714
5	12	45.88	6.01	0.73	10.0	0.20	0.833

TABLE III. Result from Experiment

V_{in}	V_{pwm1}	V_{pwm2}	f_s kHz	V_{xy}	I_{xy} (A)	V_o
20	14.0	13.8	50	10.1	0.23	8.73

The results have shown at Table IV below which are includes the theoretical, computer simulation and experiment. The Vdc input voltage is 20V and desired output power is 2W which the output voltage is maintain 10V.

TABLE IV. Comparison between Theoretical, Simulation and Experiment

Variable	Theoretical	Simulation	Experiment
Vin (dc supply)	20V	20V	20V
Vpwm1	-	10V	14V
Vpwm2	-	10V	13.8V
Vxy	-	10V	10.1V
Ixy	-	1.07A	0.23A
Vo (dc output)	10.0	9.89V	8.73V
Io	0.2A	0.198A	0.2A

When compare the results output voltage between the simulation and experiment that are shown from Table IV, the result from computer simulation is 9.89V and from the experiment is 8.73V as shown at Figure 7f.

Additional to result experiments directly measured by multimetre then consider at the output, the result for output current is 203.9m A or 0.2039A and for output voltage is 9.88V.Both of result are shown in Figure 7g and Figure 7h respectively. Therefore, the experimental results demonstrate and prove the theoretical and computer simulation.

VI. CONCLUSION

This project has presented an analysis and design dc/dc HBSPRC with LCC resonant tank and operating under resonance principal, offers are several advantages as such as zero- voltages switching, reduced switching losses and effectiveness of developed converter.

The HB SPRC with LCC as a resonant tank operation under variable input voltage and frequency control to maintain output voltage by using buck chopper concept. The analysis and implementation using step down concept has been proved where the dc output voltage is lower than dc input voltage. The teaching laboratory experiment was designed with dc/dc HB SPRC has been done and discussed. The comparison results were shown.

The computer simulation and experiment result should be compared between theoretical based on the application and desired output power. The Operating theory and the equation are also improved which come out to justify the analysis.

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