

Series-Loaded Resonant Converter DC-DC Buck Operating for Low Power

M. F. Omar*, H.C.M. Haris

Faculty of Electrical Engineering, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia

*Corresponding author, e-mail: mfawzie@gmail.com

Abstract

This paper presents the functions of Series-Loaded Resonant Converter (SLRC). Series Loaded Resonant DC-DC converter is a type of soft-switching topology widely known for providing improved efficiency. Zero voltage switching (ZVS) buck converter is more preferable over hard switched buck converter for low power, high frequency DC-DC conversion applications. Zero Voltage switching techniques will be used to improve the efficiency of current and voltage at the series loaded half-bridge rectifier. The results will be described from PSIM simulation, Programming of MATLAB calculation and hardware testing.

Keywords: Series-Loaded Resonant Converter (SLRC), Zero Voltage Switching (ZVS), Half-Bridge rectifier, PSIM simulation, MATLAB calculations

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1. Introduction

One of the trends in Power Electronics field is to get the highly efficient power supplies. Resonant converter will be used because it is simple in circuit configuration and preparation. When they are used in the production of relatively fixed applications such resonant converter used in switching power supply mode as shown on the computer, a battery charger and DC motor drive, high efficiency and low switching losses will be set as a rule.

The series loaded resonant converter (SLRC) use of one resonant capacitor (C_r) and resonant inductor in series with a MOSFET to the load. SLRC is divided into four stages contain a DC supply, resonant circuit, square wave generator, and rectifier load to give the desired output [1].

Resonant converters can be classified, depend on the source is extracted from the resonant circuit, into the three types: i) series resonant converter; ii) parallel resonant converter; and iii) series-parallel converter [2]. However, the drawback is that the series resonant converter charging voltage cannot be possibility controlled at no load.

The series loaded resonant converter usually works step-down (buck) converter [6]. Design of the series loaded converter is to maintain constant of the power, current and voltage with adjusting the switching frequency of the converter at the MOSFET.

1.1 Problem Statement

Most of the converter cannot get the constant and stable voltage because the voltage has relevant ripple. With the SLRC can solve this problem. Switching losses are directly proportional to the switching frequency [1], for example when high frequency loses the frequency switching will also be high.

DC-DC converters operate by switching input voltage at high frequencies. When a switch turns on or turn off it takes a short of time for its voltage or current to drop to zero. During this time converter switching will losses.

Hard switching occurs when the switch is turned on or turned off when the voltage or current is non-zero. When the voltage or current within the converter is switched as the voltage or current is naturally zero, soft-switching is occurring. The converter will give a slow respond time operation. This gives poor efficiency capabilities. While the efficiency was very low and therefore solving this problem can be overcome by using the resonant converter.

1.2 Literature Review

This project is to optimize the information from other research to be a better proposition than before. The information included how to implementation. Some of this information can be used as serial, parallel and series parallel resonant converter. The SLRC is formed by capacitor, inductor at the resonant tank part and a half-bridge rectifier at the output terminals making it possible to obtain the output DC. The first step was to select the circuit topology for the series-loaded resonant converter.

The advantages of SLRC are the soft switching compare to other converter topologies. The literature describes about soft-switching techniques to improve an efficiency of resonant DC-DC converters. The SLRC is very simple and easy to design.

2. Methodology

2.1 Block Diagram of SLRC DC-DC

- a. DC Input supply : 24V
The power supply used is a source from the dc power supply voltage which is received 24V. DC Power supply set is only 24V output
- b. Square wave Generator for Mosfet;
Square wave Generator for MOSFET is a using two N-channel MOSFET connector in series. Inject the pulse signal at the gate with frequency 20 kHz.
- c. Control and Driver Circuit;
 1. Control circuit contain The Controller Arduino interface with the simple programming, used to generate and get the square wave with frequency of 20 KHz.
 2. Driver Circuit contain the IC IR2110 is required to boost up the output waveform to desire voltage level to drive the MOSFET in resonant circuit.
- d. Series Loaded Resonant Converter circuit;
The converter produced by the resonant capacitor that connected series with the inductance to the load. Therefore the circuit is suitable for the step-down Voltage for low power applications.
- e. Rectifier for dc output
The component in Half bridge rectifier where four diodes connected in series and parallel.
- f. Load
The load have a capacitor and resistor connected in parallel to load.
- g. Output
Result of the waveform and value for output voltage and output current

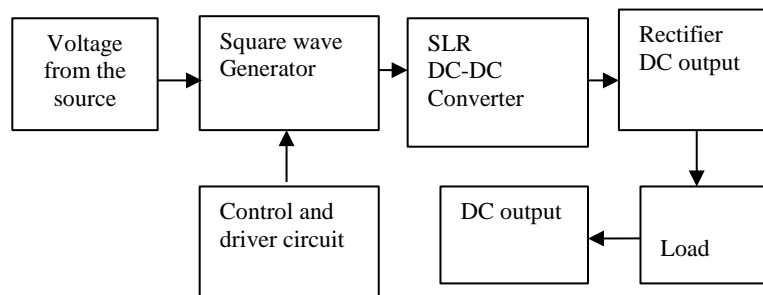


Figure 1. Block diagram of SLRC

2.2. Flow Chart Process

- a. Literature - The first block is the literature review. From this block can get the correct information and data from other journals and research that related to this project. This information can be used as a reference.
- b. MATLAB - For the second block is a Calculation SLRC using MATLAB calculation programming. This stage is to find the value of the component to the build of the hardware. All the value from the calculations can be fine after perform the MATLAB calculation programming.

- c. Simulation - For third block is a Simulate the circuit using PSIM simulation software. This stage to ensure the circuit and components is right place before the actual hardware component circuits are performed. The PSIM simulation is very important for this project, to detect the problems and the hardware components of the circuit at the starting stage. The PSIM simulation use to simulate for each electronic circuit. The PSIM simulation provides a schematic interface and a waveform.
- d. Design - This stage is design the Resonant Converter at the PCB board. The work progress requires to using a specific tool, components, material and all the data refer from the MATLAB calculation programming and the PSIM simulation of the circuit. This stage must be use and as well as capital and a very complicated work progress.
- e. Testing - When finish the designing part of the hardware at PCB board after that testing part to find the value of current and voltage and output waveform. The result can be analysed with the output waveform using the oscilloscopes.
- f. Report - For the last stage after achieve the hardware output objectives is prepare the report include the Technical paper. After finish the technical paper do a documentation and last part is do the thesis for this project. At the technical paper report, documentation and thesis have the result of the analysis, waveform, graphs and table comparison result.

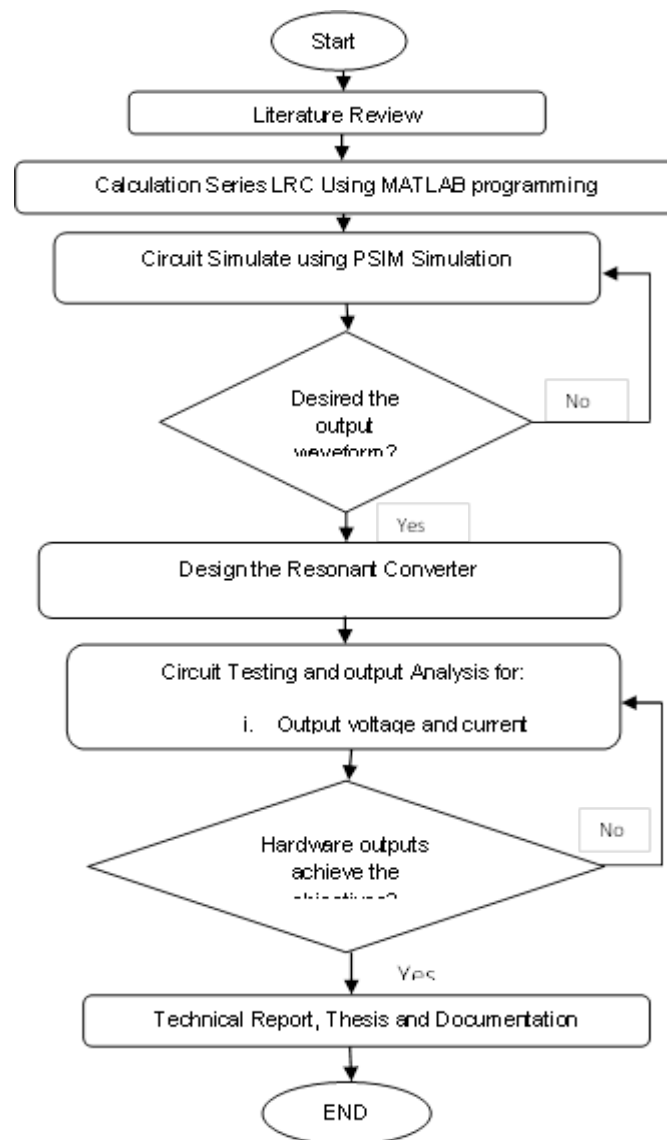


Figure 2. Flow chart process

2.3 SLRC DC-DC circuit

Figure 3 shown illustrate the combined of SLRC prototyped. In this research consisted a DC source, half-bridge, resonant part, output rectifier and load are arranged and a controller. The converter produced by the resonant capacitor that connected series with the inductance and the load. Supply voltage DC source input is connected to the MOSFET injected pulse frequencies 20 kHz. MOSFET 1 and MOSFET 2 is connected in series.

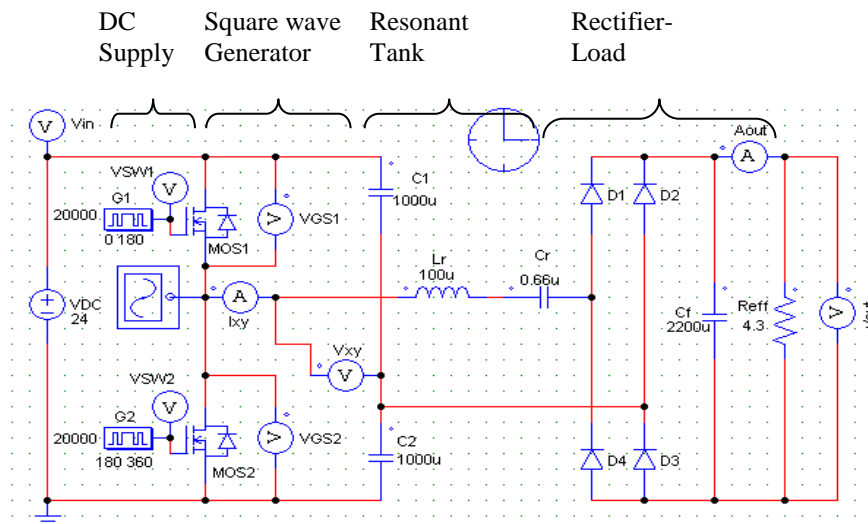


Figure 3. Series-Loaded Resonant Converter DC-DC circuit

The output to resonant circuit connected between source MOSFET 1 and drain MOSFET 2. The resonant circuit consists of and the inductance L_r and capacitor C_r that form the series-resonant circuit to maintain a continue current with zero voltage switching. The rectifier rectifies current pulses from the resonant circuit and charges the output capacitor and sources the load [5]. In the converter the resonant current rather than the voltage is rectified and smoother form the DC output and it is again assumed that the MOSFET body diodes from the half bridge anti parallel diodes.

The converter is controlled by adjusting the driver pulses to MOSFET. The advantage used a MOSFET because the component is high switching speed and MOSFET is the fastest semiconductor devices of switching because can turn on and off very fast in terms of switching. They are majority carrier devices and their operation is based on the generation and removal of an electric field [4]. When the rectifier is a current-fed, the output filter only consists of a shunt connected capacitor. This is because the filter must have the capacity to absorb sudden changes in the rectifier output current.

The operation of the rectifier it operating frequency and peak voltage or current are factors that determine what type of switches are best suited for the SLRC. The rectifier rectifies current pulses from the resonant circuit and charges the output capacitor and sources the load. The sinusoidal rectifier input current defined the operation of the circuit [1]. When the current I_{xy} is positive, diodes D1 and D4 conduct, and the rectifier input voltage V_{xy} is $+V_o$.

When the current reverses D2 and D3 are brought into conduction and the rectifier input voltage switches to $-V_o$. The rectifier input voltage is therefore, a square wave of $\pm V_o$ in phase with the sinusoidal input current. The rectifier output current is a full-wave rectifier sinusoid which is smooth by the filter capacitor C_f [3]. The capacitor at the output C_f is assumed to be large and capable of maintaining a constant output voltage across the load without relevant ripple [2].

2.4 Simulation and Analysis

Figure 4 shown the Flow Chat for MATLAB calculation, from the step of flow chat is need to Normalized the Switching frequency (w_n), and the value of (w_n) must between 0 to 2. Using the MATLAB calculation to find the value component hardware for Inductor resonant (L_r), capacitor resonant (C_r), resistance filter (R_{eff}), and Voltage output (V_o) at the load of this project.

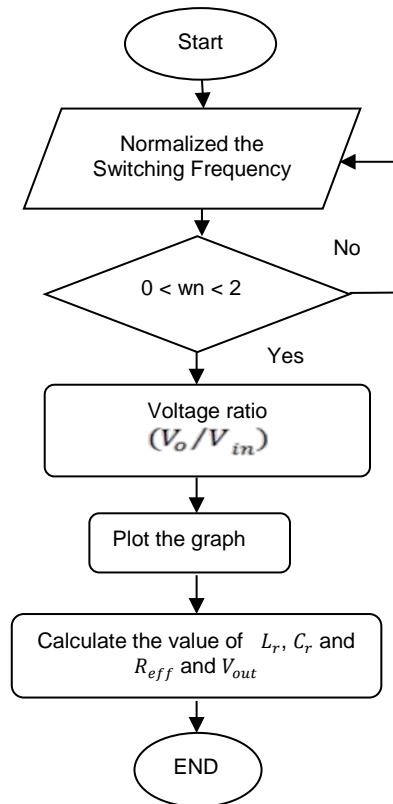


Figure 4. MATLAB Flow chart calculation

Figure 5 is illustrate graph Voltage conversion ratio between the V_{out}/V_{in} for the series-loaded resonant converter with; $Q = 1, 2, 3, 4, 5$. The graph of Figure 5 gets from the MATLAB calculation.

$$Q1 = \frac{\omega_0 L}{R} \leftarrow \text{Low load} \quad (1)$$

$$Q5 = \frac{\omega_0 L}{R} \leftarrow \text{High load} \quad (2)$$

The calculation from the value of frequency and $m1$.

$$\frac{V_o}{V_{in}} = m1 \quad (3)$$

Where max $m1 = \frac{V_o}{V_{in}} = 0.5$ (for half bridge) and 1.0 (for full bridge).

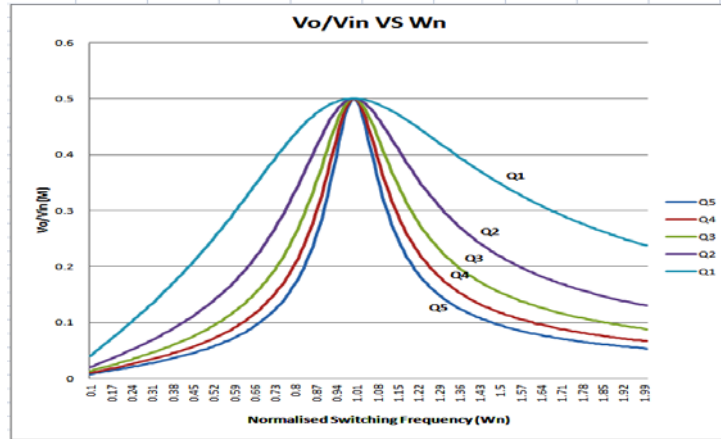


Figure 5. Voltage conversion ratio $\frac{V_o}{V_{in}}$ for the Series-loaded resonant converter with $Q = 1, 2, 3, 4, 5$.

From calculation for frequency = 20 kHz, $V_{in} = 24V$, $V_o = 12V$, and $Q = 5$. $\frac{V_o}{V_{in}} = 0.5$.

Graph $\frac{V_o}{V_{in}}$ versus ω_n are shown in Figure 5. From the graph, value of W_n suitable is 1.00 and Table 1 is shown calculation result using MATLAB calculation.

Table 1. Value using MATLAB calculation

w_n	0.96	0.97	0.98	0.99	1.00	1.01	1.02
m_1	0.446	0.468	0.485	0.496	0.500	0.496	0.486
W_o	130900	129600	128200	126900	125700	124400	123200

From the Table 1 shown the value $m = 0.5$, $\omega_n = 1$, and $\omega_o = 125700$. It is suitable to choose and the result from calculation of L_r , C_r and V_o by MATLAB shown in Table 2.

Table 2. Result the component value from MATLAB calculation

V_{in}	f_0	L_r	C_r	R_{eff}	V_o
24.0V	20.0kHz	100uH	0.63uF	3.1Ω	12.0V

2.5 Equivalent Circuit and Analysis

Figure 6 shown the equivalent circuit of LC configuration half bridge SLRC as before sinusoidal input voltage and the voltage fed rectifier is replaced with an effective input resistance [4]. In order to understand how the SLRC's operate, it is first necessary to analyze a series loaded resonant circuit. A series-resonant circuit is a commonly studied circuit in electrical engineering. The circuit consists of a series connected source, inductor and capacitor and is illustrated.

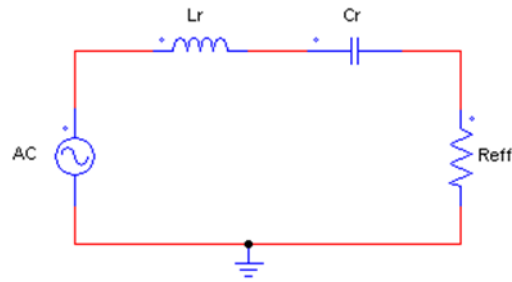


Figure 6: LC configuration half bridge SLRC

$$\omega_0 = \frac{1}{\sqrt{LrCr}} \quad (4)$$

The characteristic impedance of the resonant circuit is determined by;

$$Z_0 = \sqrt{\frac{Lr}{Cr}} \quad (5)$$

While the voltage conversion ratio is calculated by:

$$\left| \frac{V_o}{V_{in}} \right| = \frac{\frac{1}{2}}{\left| 1 + j\frac{\pi^2}{8} Q \left[\left(\frac{\omega}{\omega_0} \right) - \left(\frac{\omega_0}{\omega} \right) \right] \right|} \quad (6)$$

And the R_{eff} is define as;

$$R_{eff} = \frac{8R}{\pi^2} \quad (7)$$

Zero Voltage Switching where $f_s > f_0$, (in practical, $Q = 5$)

$$Q = \frac{\omega_0 L}{R} \quad (8)$$

2.6 Design and Hardware Circuit

Hardware design assists by PCB Wizard software where the components suitable install at PCB board. Figure 7 illustrate the PCB wizard circuit layout for the SLRC circuit and Figure 8 illustrate the hardware circuit layout at the PCB board.

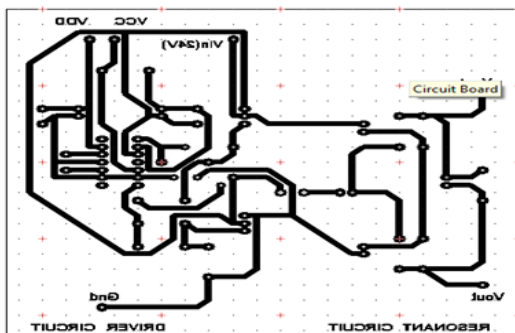


Figure 7. PCB Wizard circuit layout.



Figure 8. Hardware circuit layout

3. Results and Discussion

The results of PSIM simulation and hardware testing will be shown the by the Figure 9 to 17. The Figures were shown the voltage and current waveform from driver circuit, resonant tank, Controller the Arduino interface Programming Output, MOSFET and load (V_{out}).

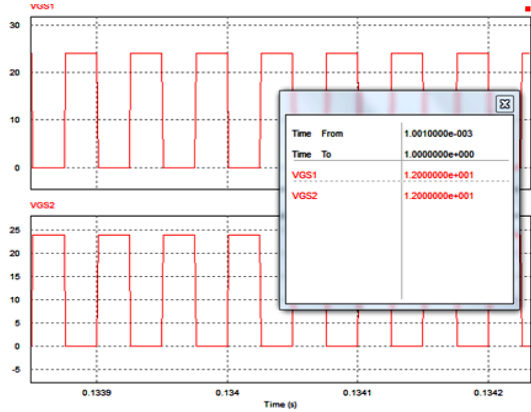


Figure 9. PSIM simulation result waveform for MOSFET1 (VGS1) and MOSFET2 (VGS2) circuit output

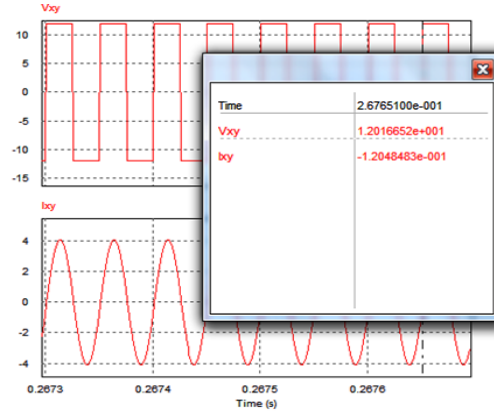


Figure 10. PSIM simulation Voltage (V_{xy}) and Current (I_{xy}) result on resonant circuit output

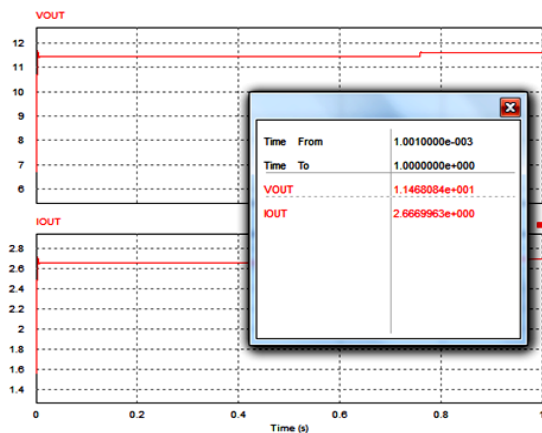


Figure 11. PSIM simulation result Voltage Out (V_{out}) and Current Out (I_{out}) at the load

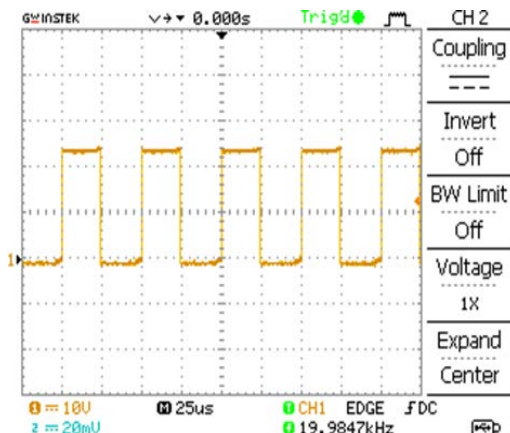


Figure 12. Hardware testing results Voltage (V_{xy}) results at resonant circuit output

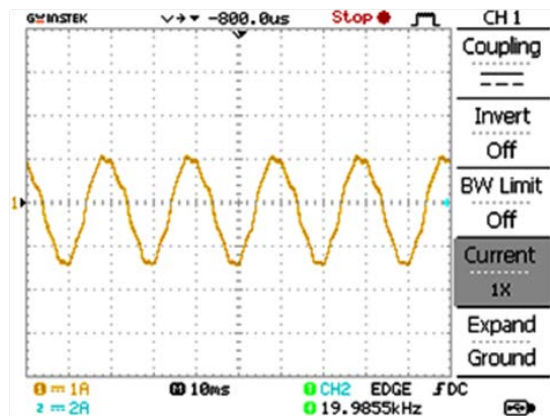


Figure 13. Hardware testing results Current (I_{xy}) result at resonant circuit output

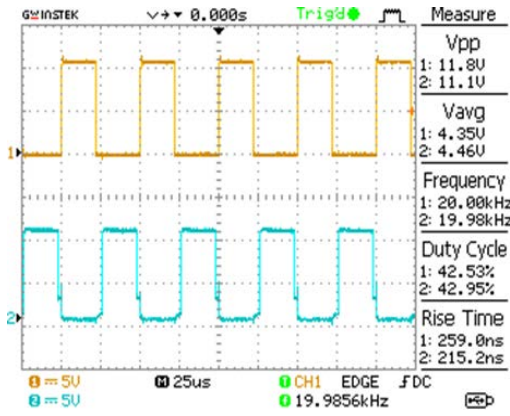


Figure 14. Hardware testing result voltage waveform at MOSFET1 (VGS1) circuit output.

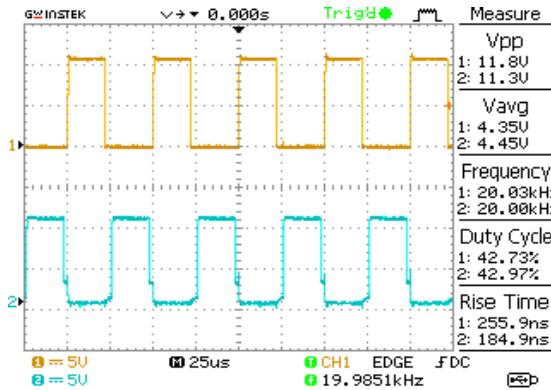


Figure 15. Hardware testing result voltage waveform at MOSFET2 (VGS2) circuit output

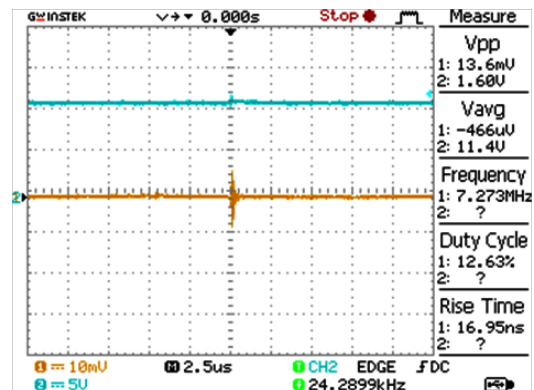


Figure 16. Hardware testing result Voltage Output (V_o) at load

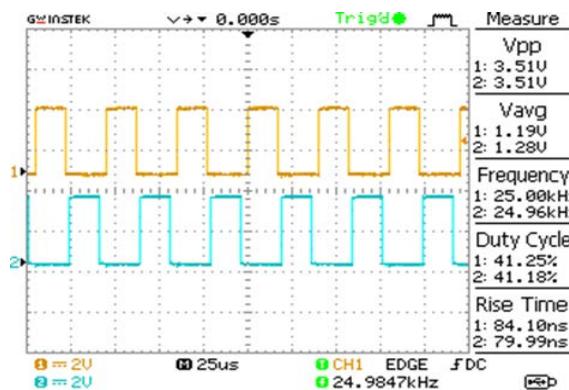


Figure 17. The Arduino Controller interface Programming Output Waveform

Table 3 is shown the comparison value of output voltage (V_{out}) from MATLAB calculation, PSIM simulation and hardware testing result. Table 4 is shown the summary result of hardware testing result component value and load.

Table 3. Value (V_{out}) from MATLAB Calculation, PSIM Simulation and Hardware Testing Result

V_{out} MATLAB calculation result	V_{out} PSIM simulation result	V_{out} Hardware testing result
12.0V	11.47V	11.40V

Table 4. Summary of Hardware testing result component value and load (V_{out})

Power Supply Side	Input Voltage		Switching Frequency	Voltage Dividing Capacitance C1&C2
		24 V		20 kHz
Resonant Tank	Resonant Inductance(Lr)	Resonant Capacitance(Cr)	Characteristic Impedance(Z_o)	Resonant Frequency(f_o)
	100uH	0.66uF	12.57 Ohm	19.98kHz
Load Side	Filter Capacitance	Load		
	2200 uF	11.4 V		

4. Conclusion

For this paper can be concluded that the Series-Loaded Resonant Converter (SLRC) design of step-down the voltage from $V_{in}=24V$ to $V_{in}= 11.4V$ and constant of the output voltage V_o . The analysis of the capacitor C_f at the output can be maintain and constant the voltage at the V_o with the small ripple voltage. With it the efficiency of the output voltage can be increased. The concept was to incorporate resonant tanks in the converters to create oscillatory voltage and current waveform and then Zero Voltage Switching (ZVS) can be developed when inject at the gate MOSFET the pulse signal with frequency 20kHz at the MOSFET 1 and MOSFET 2.

MATLAB calculation, Controller Arduino interface Programming, , PSIM simulation and PCB wizard software is very important to design this project. The design of PCB circuit layout from the PCB wizard and get the value of component from MATLAB calculation. After this use the PSIM simulation with the value of component and circuit and run the simulation to find the output same like a MATLAB calculation. After PSIM simulation run and get the ideal output, the hardware was to design.

5. Recommendation for the Further Work

Recommendation for the further work for this project, this circuit can be added to the auto coupler. This circuit can be adding feedback system in the circuit and it is can will protect from the false. This circuit in the closed loop system. By adding this control system the circuit is output waveform in the designation of the voltage or power lead and the efficiency of the system.

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