

# Experimental Study and Comparative Analysis of CLL-T and LCL-T Series Parallel Resonant Converter with Fuzzy/ PID Controller

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**Abstract:** A Series Parallel Resonant Converter with LCL-T and CLL-T configuration has been simulated and presented in this paper with closed loop operation. The limitations of two element resonant topologies can be overcome by adding a third reactive element termed as modified Series Parallel Resonant Converter (SPRC). A three element LCL-T SPRC working under load independent operation (voltage type and current type load) is presented in the paper. The analysis is carried out using the state space approach and the regulation of output voltage is done by using Fuzzy Logic Controller (FLC). The proposed approach is expected to provide better voltage regulation for dynamic load conditions. A prototype 300 W, 100 KHz converter is designed and built to experimentally demonstrate. The simulated and experimental results shows that the output of converter is free from the ripples and the converter can be used for many air borne application.

**Keywords:** Resonant Converter, Fuzzy logic, Control System, MATLAB, Power Electronics.

## 1.Introduction

The developments of the resonant converters are increasing now a day due its performance. The research in this field has been shown more interest by many researchers in developing the load independent converters using various concepts. The series and parallel Resonant Converter (SRC and PRC respectively) circuits are the basic resonant converter topologies with two reactive elements. The merits of SRC include better load efficiency and inherent dc blocking of the isolation transformer due to the series capacitor in the resonant network. However, the load regulation is poor and output-voltage regulation at no load is not possible by switching frequency variations. On the other hand, PRC offers no-load regulation but suffers from poor load efficiency and lack of dc blocking for the isolation transformer. It has been suggested to design Resonant Converter with three reactive components for better regulation. In order to overcome the above limitations, the Series Parallel Resonant Converter (SPRC) is found to be reliable due to various inherent advantages. The LCL tank circuit based DC-DC Resonant Converter has been experimentally demonstrated and reported by many researchers [1-2].

Mangesh Borage et al [3] have demonstrated an LCL-T half bridge resonant converter with clamp diodes, in which the output voltage of constant current power supply increases linearly. Therefore a constant-voltage limit must be incorporated in the converter. In order to get these operations the clamp diode is required. The feed back control circuit has not been considered. Later, Mangesh Borage et al [4] have

demonstrated the LCL-T RC with constant current supply operated at resonant frequency. The converter operated at fixed resonant frequency and its analysed using state space approach. Mangesh B. Borage et al [5] have demonstrated the characteristics of LCL-T Resonant converter using Asymmetrical duty cycle (ADC). The converter operated at fixed resonant frequency and its analysed using state space approach.

Vijayakumar Belaguli et al [6] have experimentally demonstrated with independent load when operated at resonant frequency, making it attractive for application as a constant voltage (CV) power supply. It has been found from the literature that the LCL tank circuit connected in series-parallel with the load and operated in above resonant frequency improves the load efficiency and independent operation. Paolo Mattavelli et al [7] have described the fuzzy logic control (FLC) for DC-DC converter. This control technique relies on the human capability to understand the system's behavior and is based on qualitative control rules. The FLC approach with same control rules can be applied to several dc-dc converters. However, some scale factors must be tuned according to converter topology and parameters. The author used the control technique for Buck-Boost converter and demonstrated. J.M. Correa et al [8] have demonstrated a DC/AC series resonant converter with fixed load considering fuzzy control approaches.

Lakshminarasamma.N et al [9] have demonstrated active clamp ZVS DC-DC converter. The steady state stability analysis was presented for ZVS Buck converter. There is no possible of load independent operation. The converter operates at duty cycle  $>0.5$ , above its operation the converter fails to instability. S.Arun et al [10] the ZVS LCL push-pull Converter with closed loop operation was demonstrated using PI controller. Resonant Topology like LCL and LLC Resonant Converter are compared with open loop and closed loop. Here the load variation and load independent operation not presented, and there was no static and dynamic analysis. Later, Martin P.Foster et al [11] have demonstrated CLL half bridge Resonant Converter with open loop operation. The ac equivalent circuit analysis and fundamental mode approximation (FMA) analysis was derived used to the modeling the converter and compared. The evaluation of static and dynamic performance was not provided.

Later T.S.Sivakumaran et al [12] have been developed a CLC SPRC using FLC for load regulation and line regulation. The performance of controller has been evaluated and found that the load independent operation may not be possible. The FLC based Zero Voltage Switching quasi-resonant converter has been demonstrated in [13-15]. The load independent operation was not realized and power handling capacity of the

converter is found to be poor. C.Nagarajan et al [16] have simulated an LCL-T SPRC using FLC and PID controller. The performance of controller has been found to be better when the fuzzy controller has been considered. The harmonic spectrum and dynamic analysis for RLE load are presented.

It is clear from the above literatures that the output voltage regulation of the converter against load and supply voltage fluctuations have important role in designing high-density power supplies. The LCL-T SPRC is expected to have the speed of response, voltage regulation and better load independent operation. Keep the above facts in view, the LCL-T SPRC has been modeled and analyzed for estimating various responses. The closed loop state space model has been derived and simulated using MATLAB/Simulink. The steady state stability analysis of the converter is presented. A prototype 300 W, 100 kHz the LCL-T SPRC and CLL-T SPRC is implemented and the experiment results are compared with the simulation results. The simulation results agree with the experimental results.

## 2. Proposed LCL-T Series Parallel Resonant Converter With Fuzzy Control Circuit

The block diagram of LCL-T SPRC with FLC is shown in Fig.1. The first stage converts the dc voltage to a high frequency ac voltage. The second stage of the converter is to convert the ac power to dc power by suitable high frequency rectifier and filter circuit. Power from the resonant circuit is taken either through a transformer in series with the resonant circuit or series in the capacitor comprising the resonant circuit. In both the cases the high frequency feature of the link allows the use of a high frequency transformer to provide voltage transformation and ohmic isolation between the dc source and the load.

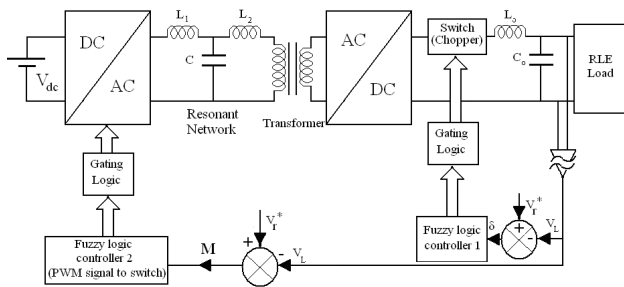


Fig.1 Block Diagram of LCL-T Series Parallel Resonant Converter

In LCL-T SPRC the load voltage can be controlled by varying the switching frequency or by varying the phase difference between the inverters. The phase domain control scheme is suitable for wide variation of load condition because the output voltage is independent of load. The dc current is absent in the primary side of the transformer and there is no possibility of current balancing. Another advantage of this circuit is that the device currents are proportional to load current. This increases the efficiency of the converter at light loads to some extent because the device losses also decrease with the load current. If the load gets short at this condition, very large current would flow through the circuit. This may damage the switching devices.

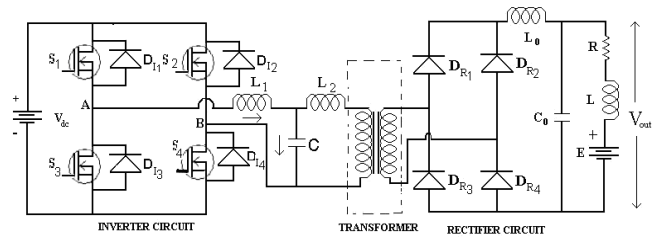


Fig.2. LCL-T Series Parallel Resonant Converter

A schematic diagram of full-bridge LCL-T SPRC is shown in Fig.2. The resonant circuit consists of series inductance  $L_1$ , parallel capacitor  $C$  and series inductance  $L_2$ . The MOSFET switches  $S_1 - S_4$  are used to base /gate turn-on and turn-off. Similarly anti-parallel diodes  $D_{11}$  to  $D_{14}$  are also used to regulate the circulating current. The MOSFET ( $S_1$ ) and its anti parallel diode ( $D_{11}$ ) act as a bidirectional switch. The gate pulses for  $S_1$  and  $S_2$  are in phase but 180 degree out of phase with the gate pulses for  $S_3$  and  $S_4$ . The positive portion of switch current flows through the MOSFET and negative portion flows through the anti-parallel diode. The RLE load is connected across bridge rectifier via  $L_0$  and  $C_0$ . The voltage across the point AB is rectified and fed to RLE load through  $L_0$  and  $C_0$ . For the analysis it is assumed that the converter operates in the continuous conduction mode and the semiconductors have ideal characteristics.

### 3. Stability Analysis of LCL-T Sprc And CLL-T Sprc Using State Space Technique

### 3.1 State Space model for LCL-T SPRC

The equivalent circuit of LCL-T SPRC is shown in Fig.3. The mathematical modeling using state space technique can be obtained assuming all the components to be ideal.

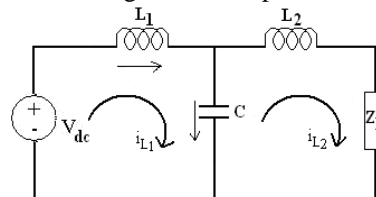


Fig.3 Equivalent Circuit Model of LCL-T SPRC

The Transfer Function for the LCL-T SPRC is given below from fig.3.

$$\frac{V_0(s)}{V_i(s)} = \frac{Z_L}{L_1 L_2 C s^3 + L_1 Z_L C s^2 + (L_1 + L_2)s + Z_L} \quad (1)$$

The State Space model for LCL-T SPRC find from the equation (1)

$$\frac{Y_0(s)}{u_i(s)} = \frac{Z_L}{L_1 L_2 C s^3 + L_1 Z_L C s^2 + (L_1 + L_2)s + Z_L} \quad (2)$$

Taking inverse laplace transform (4) and the state space equations are

$$\dot{X}_1 = x_1$$

$$\dot{X}_2 = x_3$$

$$\dot{X}_3 = \frac{-Z_L}{CL_L} x_1 - \left( \frac{L_1}{CL_L} + \frac{L_2}{CL_L} \right) x_2 - \frac{L_1 Z_L}{L_1 L_2} x_3 + \frac{Z_L}{CL_L} u_i(s)$$

The State Space model for LCL-T SPRC is

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ \frac{-Z_L}{CL_1L_2} & \frac{-1}{CL_2} - \frac{1}{CL_1} & \frac{-Z_L}{L_2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \frac{Z_L}{CL_1L_2} \end{bmatrix} [u_i(s)] \quad (3)$$

The output equation is

$$y_0 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} \quad (4)$$

#### B. State Space model for CLL-T SPRC

The equivalent circuit of CLL-T SPRC is shown in Fig.4. The State Space equation can be derived from the transfer function (5)

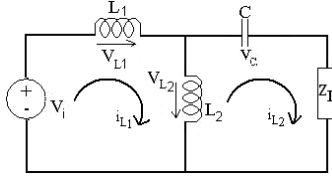


Fig.4 Equivalent Circuit Model for CLL-T SPRC

The Transfer Function for the CLL-T SPRC is given below from fig.4.

$$\frac{Y_0(s)}{u_i(s)} = \frac{Z_3 Z_L}{Z_1 Z_2 + Z_1 Z_3 + Z_1 Z_L + Z_2 Z_3 + Z_3 Z_L} \quad (5)$$

Substitute  $Z_1, Z_2, Z_3$  in equation (8)

$$\frac{Y_0(s)}{u_i(s)} = \frac{L_1 Z_L s^2}{\frac{(L_1 + L_2)s}{C} + \frac{Z_L}{C} + L_1 L_2 s^3 + L_1 Z_L s} \quad (6)$$

Taking inverse Laplace transform in equation (6) and the state space equations are

$$\dot{X}_1 = x_2$$

$$\dot{X}_2 = x_3$$

$$\dot{X}_3 = -\frac{(L_1 + L_2)}{CL_1L_2}x_2 - \frac{Z_L}{CL_1L_2}x_1 - \frac{Z_L}{L_2}x_3 + \frac{Z_L}{L_2}\ddot{U}$$

In above state space equations are written as in matrix form.

The State Space model for CLL-T SPRC is

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ \frac{-Z_L}{CL_1L_2} & \frac{-L_1 + L_2}{CL_1L_2} & \frac{-1}{L_2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \frac{Z_L}{L_2} \end{bmatrix} U \quad (7)$$

The output equation is

$$y_0 = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} \quad (8)$$

## 4. Results And Discussion

### 4.1 Design Parameters of the Converter

For the design of LCL-T SPRC [6], the design specifications are: minimum and maximum value of dc voltage, maximum

output current ( $I_o$ ), corresponding to the full-load condition and switching frequency ( $f_s$ ). In the analysis of previous sections, the transformer turns ratio ( $N_1/N_2$ ) was assumed to be unity. It is desired to design the converter with the following specifications:

TABLE. 1 PARAMETERS OF THE SPRC

S.no	Parameter	Value
1	Power output	300W
2	Minimum input voltage	100V
3	Minimum output voltage	100V
4	Maximum load current	3A
5	Maximum overload current	4A
6	Transformer Turns ratio	1
7	Switching frequency ( $f_s$ )	100KHz
8	Series Inductance $L_1, L_2$	39.18 $\mu$ H
9	Parallel Capacitance (C)	66 nF
10	Load Inductance ( $L_o$ )	1mH
11	Load Capacitance ( $C_o$ )	650 $\mu$ F

The values used for all the elements are presented. These values were obtained using a design procedure (Borage *et al.*, 2009) to assure resonance for almost different power ranges (load-independent design) and also to limit the current and voltage peak values. The fuzzy controller used is robust to parameter variations as well as for a wide load operating conditions. The simulation and implementation are carried out for 300 W load power. The load used on the tests is composed of a series connection of a resistor and a small inductor.

### 4.2 Fuzzy Logic Control (FLC)

Fuzzy control involves three stages: fuzzification, inference or rule evaluation and defuzzification. SPRC is modeled using MATLAB software. Fuzzy control is developed using the fuzzy toolbox. The fuzzy variables 'e', 'ce' and ' $\Delta u$ ' are described by triangular membership functions. Five triangular membership functions are chosen for simplicity. Table 2 shows the fuzzy rule base created in the present work based on intuitive reasoning and experience. Fuzzy memberships NB, NS, Z, PS, PB are defined as negative big, negative small, zero, positive small, and positive.

The control rules that relate the fuzzy output to the fuzzy inputs are derived from general knowledge of the system behavior, perception and experience. It can be inferred that the output voltage is far from the reference value, then the change of switching frequency ( $\Delta u$ ) must be large so as to bring the output to the reference value quickly. The output voltage approaches the reference value, and then a small change of switching frequency is necessary and if the output voltage is near the reference value and is approaching it rapidly, then the frequency must be kept constant so as to prevent overshoot. It is also seen that if the output voltage changes even after reaching the reference value then the change of frequency must be changed by a small amount to prevent the output from moving away

TABLE.2.FUZZY RULES

Error (e)		NB	NS	Z	PS	PB
Change in error (ce)	NB	NB	NB	NB	NM	Z
	NS	NB	NM	NS	Z	PM
	Z	NB	NS	Z	PS	PB
	PS	NM	Z	PS	PM	PB
	PB	Z	PM	PB	PB	PB

The Fuzzy controller1 changes the Modulation Index (MI) according to the output and reference voltage which is give to the PWM unit. The PWM generate and produces the pulses and given to the inverter switches, there by the inverter regulate the voltage. Fig.5 (a).show that the generated pulses form the FLC that's to be given to the inverter circuit.

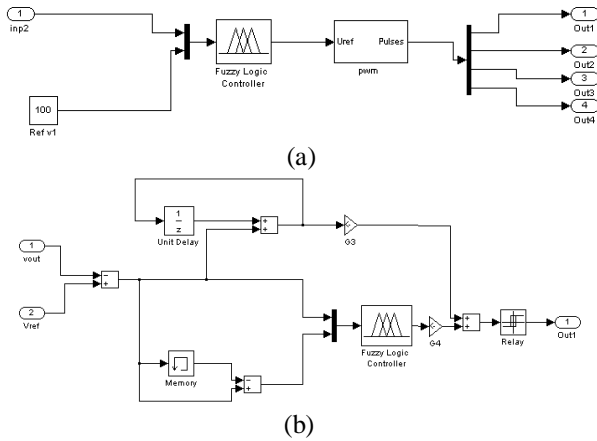


Fig.5 Structure of the fuzzy controller for (a) inverter side, (b) rectifier side.

The fuzzy controller2 changes the duty cycle of the chopper according to the output voltage and reference voltage respectively. Furthermore the chopper regulates the output voltage. The structure of the fuzzy controller2 rectifier side are shown in Fig.5.(b).

#### 4.3. Simulation Results

The closed loop simulation using FLC is carried out using MATLAB/Simulink software. Depending on error and the change in error, the value of change of switching frequency is calculated. The Fuzzy set parameters instruction and function blocks available in MATLAB are used to update the new switching frequency of the pulse generators. The entire system is simulated with a switching frequency of 100 KHz.

The LCL-T SPRC and CLL-T SPRC have been simulated using MATLAB/Simulink toolbox. The fuzzy controller has been designed and simulated wave forms of resonant voltage, resonant current and output voltage are shown in below figures. The fuzzy controller performance is compared with the resonant topologies.

##### 4.3.1 CLL-T SPRC using Fuzzy Logic Controller Fed with RLE Load

The fuzzy controller has been designed and simulated wave forms of resonant voltage, resonant current and output voltage

shown in Fig.6-8. The CLL-T SPRC performance was also compared with the converters performance. The slight droop in the resonant characteristics is due to the increase in conduction losses in the bridge inverter and resonant network. The CLL-T SPRC is operated in resonance frequency. It is observed that the voltage and current are not match with the phase of the resonance.

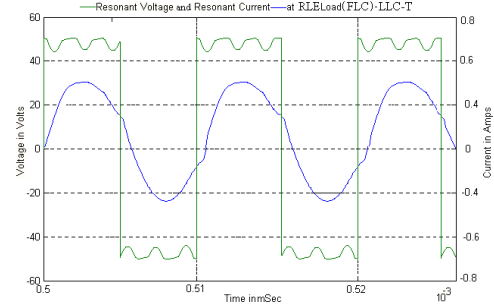


Fig.6 Resonant current and resonant voltage for  $V_r=100V$  (CLL-T SPRC with FLC fed RLE Load)

It is clearly seen form the above Fig.6 the resonant voltage and current contains harmonic, this harmonics effect relatively hard for the whole circuit, because non-linear loads affect the resonant circuit. The voltage wave form for capacitor is shown in Fig.7.

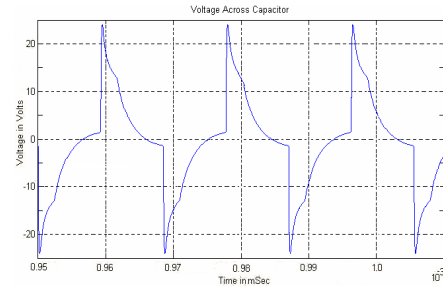


Fig.7 Voltages across Parallel Capacitor (C) (CLL-T SPRC with FLC fed RLE Load)

It can be seen from the above Fig.7 the capacitor voltage is not zero during the interval time. The current through inductor  $L_1$  is shown in the below Fig.8.

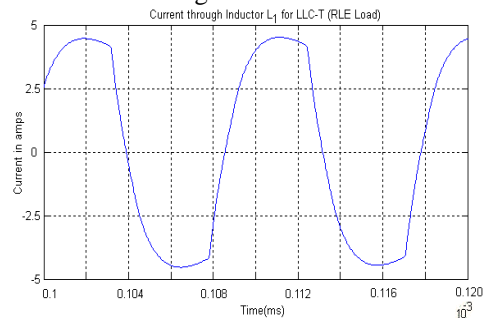


Fig.8 Current through Inductance  $L_1$  (CLL-T SPRC with FLC fed RLE Load)

The current are measured through inductor  $L_1$ . It can be seen that the peaks are relatively high with constant level are shown. It is clearly seen form the Fig.9 output voltage harmonic, this harmonics effect relatively hard for the whole circuit, because non-linear loads affect the resonant circuit.

Fig.9 shows the harmonic spectrum of the output voltage. It is observed that the settling time in FLC is 0.01 sec. The steady state error for by using the FLC is 0.004 V. The result is justified that settling time of output voltage high compared to

LCL-T PSRC. The THD value is 9.25 %.The fuzzy logic controller is suppressing the noise in greater manner.

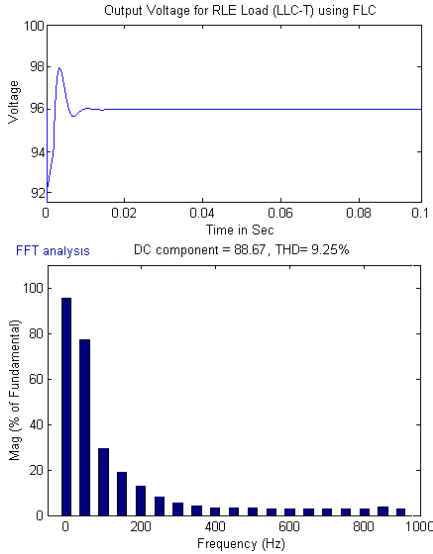


Fig.9 Output voltage and Harmonic Spectrum for RLE load (PID.FLC) for  $V_r=100V$  (CLL-T SPRC with FLC fed RLE Load)

#### 4.3.2 LCL-T SPRC using Fuzzy Logic Controller Fed with RLE Load

The resonant current and resonant voltage for different load condition were estimated and shown in Fig.10-13. The overshoot and settling time is less compared to other converters and the response is oscillatory. It is seen that the settling time of output voltage is more than that of the settling time in CLL-T. It is clearly shown in that the inverter output as pure square wave without any harmonics and with Resonance frequency.

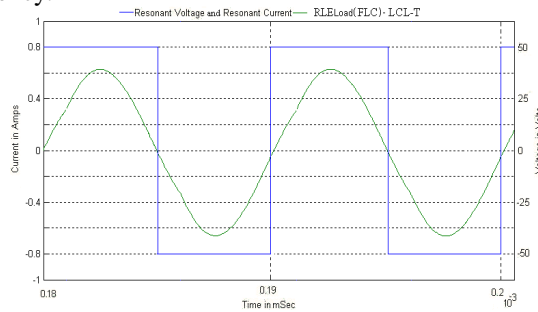


Fig.10 Resonant current and resonant voltage for  $V_r=100V$  (LCL-T SPRC with FLC fed RLE Load)

It can be seen from this above Fig.10 that the after an initial transient the resonant voltage and resonant current are good accuracy, showing a good tracking performance of the controller. The resonant current contains low harmonic and it presents a good sinusoidal shape. One can conclude that the controller is capable of operating under different load condition, proving its applicability for non linear load cases.

Fig.11 shows the voltage across parallel capacitor waveform at steady state. It is clearly seen that the current contains with any distraction. However, the drop in rectifier side, reverse recovery time and leakage inductance, the capacitor voltage during interval is exactly zero. Due to this condition conduction loss and switching loss in the inverter is very low.

The Fig.12 shown the inductor current  $L_1$  and the current are quite sinusoidal as the converter operates in the resonance frequency. It is almost sinusoidal due to the operating frequency is virtually match with the resonance frequency. In this condition the circuit has a good margin for zero voltage switching operation, providing good response, while the almost sinusoidal current waveform just allows for an extremely low EMI generation.

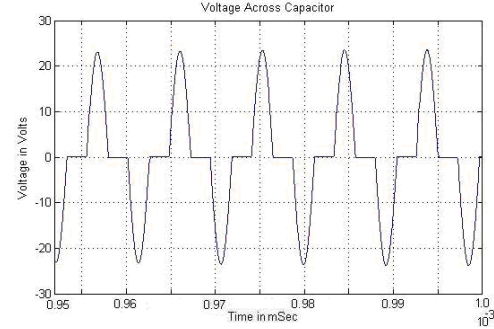


Fig.11 Voltages across Parallel Capacitor (C) (LCL-T SPRC with FLC fed RLE Load)

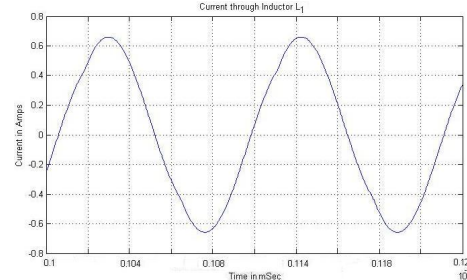


Fig.12 Current through Inductance  $L_1$  (LCL-T SPRC with FLC fed RLE Load)

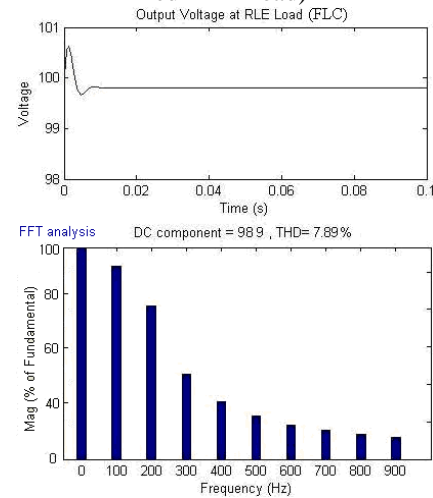


Fig.13 Output voltage and Harmonic Spectrum for RLE load (PID.FLC) for  $V_r=100V$  (LCL-T SPRC with FLC fed RLE Load)

The output voltage with THD is presented in Fig.13. It is observed that the closed loop system regulates the output voltage with settling time of 0.01 sec. for FLC. Also the percentage overshoot in output voltage is reduced to 1V. The THD is found to be 7.89 % for FLC. The result justifies that settling time of output voltage in CLL-T SPRC is more than that of the settling time in LCL-T SPRC.



The performance of resonant topologies like LCL-T SPRC and CLL-T SPRC response have been estimated and provided in Table 3. It is seen that the Fuzzy logic based closed loop controller in LCL-T SPRC provides better settling time. This ensures that the system can be controlled effectively with feedback.

Table 3. Comparative evaluation of transient and steady state performances by using FLC

Resonant Topologies	Settling Time in Sec	% Over Shoot	Steady state error
LCL-T	0.01	1V	0.001
CLL-T	0.025	3V	0.004

It is clear from the above table shows that the peak overshoot is eliminated and the settling time is much lower with the fuzzy control strategy in LCL-T SPRC. The measurement noise is highly suppressed. It is also obvious that the settling time of different resonant topologies has been compared and concluded that FLC has got better performance in LCL-T SPRC.

#### 4.4 Stability Analysis of CLL-T SPRC

Frequency response plot for CLL-T SPRC are shown in Fig.14. The plot drawn from the state space model equations (3 and 4). It is concluded that the CLL-T converter circuit is unstable for the system parameters variations. Its clearly shows that the CLL-T converter is unstable, the phase margin is about  $\alpha$  and the gain margin is very large.

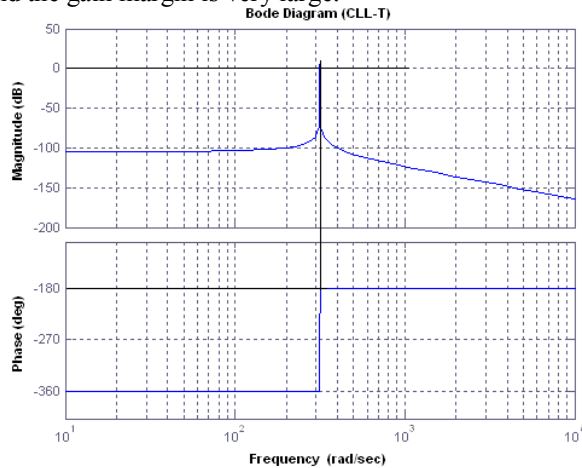


Fig.14 Frequency response of CLL-T SPRC

#### 4.5 Stability Analysis of LCL-T SPRC

The bode plot drawn for LCL-T SPRC from the state space model equations (7 and 8). It is concluded that the LCL-T converter circuit is stable for the system parameters variations. The frequency response of the LCL-T SPRC is shown in Figure 6.6. Its clearly shows that the LCL-T converter is Stable, the phase margin is about  $35^\circ$  and the gain margin is approximately 17dB.

#### 5 Experimental results

The SPRC is fabricated and tested. A prototype CLL-T and LCL-T SPRC is operating at 300 W, 100 kHz was designed.

Microcontroller P89V51RD2 is used to generate driving pulses, these pulses are amplified using the driver IC IR2110, the IRF840 MOSFETs are used as the switches in the bridge converter. The diodes MUR 4100 are used for the output bridge rectifier. The fuzzy controlling program is implemented by this microcontroller. Fuzzy program is programmed using C and compiled by KAIL compiler which is embedded in microcontroller.

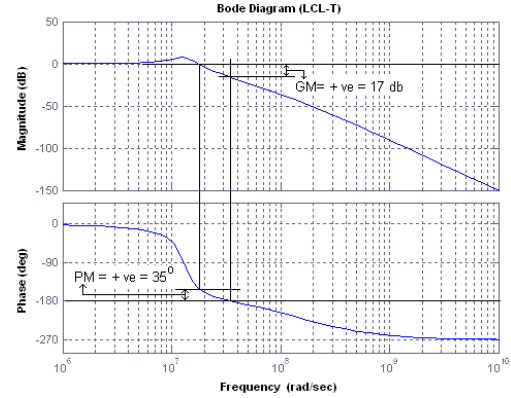


Figure 15 Frequency response of CLL-T SPRC

The Fuzzy algorithm execution should not take more than 1.5ms. The sampling frequency is 1 KHz. A drop in the output voltage level triggers the fuzzy controller to increase the output voltage of the inverter by modifying the duty cycle of the inverter switches.

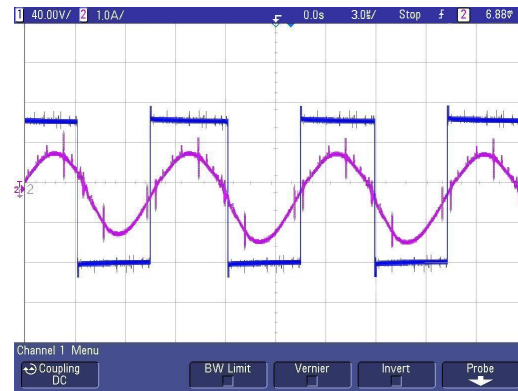


Fig.16. CH1: Resonant Voltage [Volt. Scale: 40 V/div.].CH2: Resonant Current [Amp. Scale: 0.5A/div.] for CLL-T SPRC

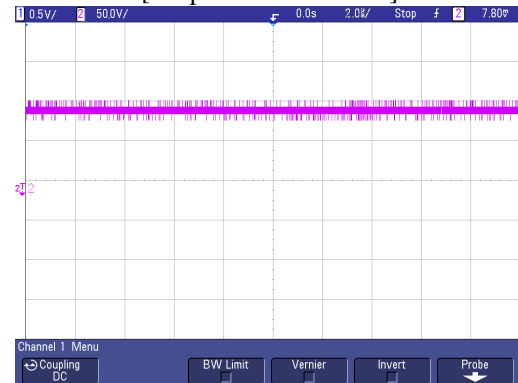


Fig.17. Output voltage for CLL-T SPRC (CH1: Output Capacitor Voltage [Volt. Scale: 50 V/div.])

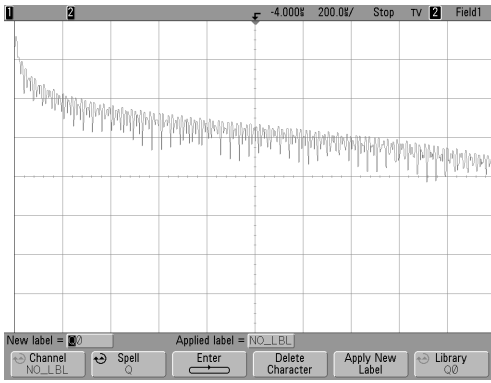


Fig.18. Experimental FFT spectrum for output voltage

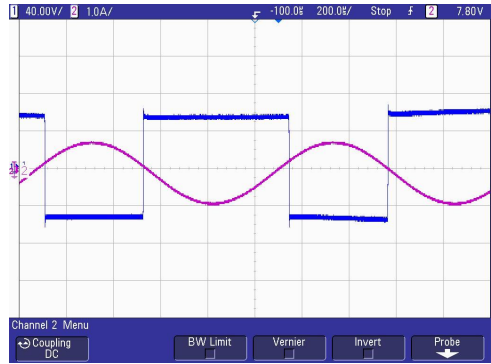


Fig.19. CH1: Resonant Voltage [Volt. Scale: 40 V/div.].CH2: Resonant Current [Amp. Scale: 0.5A/div.] for LCL-T SPRC

The above figures shown the fuzzy controller output signal for this test. These figures show the good dynamic performance of the controller. It is clearly seen from the above Fig.16 and 17 the resonant voltage, resonant current and output voltage contains harmonic, this harmonics effect relatively hard for the whole circuit, because non-linear loads affect the resonant circuit. Fig.19 and 20 presents the inverter voltage, inverter current and output voltage for LCL-T SPRC, its measure from the point A and B of the bridge inverter. It is clearly shown in Fig.19 that the power losses in the occurrence of the turn on switching are maintained very low by means of the resonant operation i.e during the switching both the voltage and current are minimum.

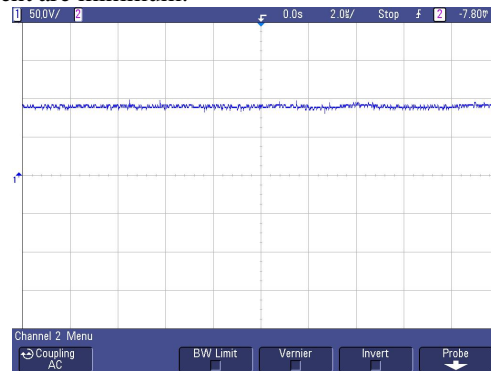


Fig.20. Output voltage for LCL-T SPRC (CH1: Output Capacitor Voltage [Volt. Scale: 50 V/div.]

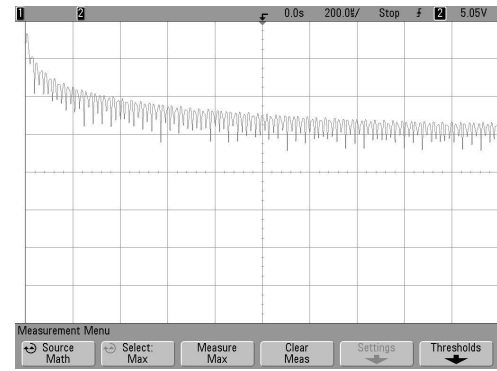


Fig.21. Experimental FFT spectrum for output voltage

Fig.20 it can be seen from this figure that the current contains low harmonics and it presents a nearly sinusoidal shape. The controller shows the good performance of the whole design. One can conclude that the controller is capable of operating under load- independent operation, again, it can be seen that the output follows the reference with good accuracy and better dynamic performances. The LCL-T SPRC is verified by simulation and experimental studies. It is clearly seen from the Table 4, the experimental results shows the theoretical values and the output voltage is seen to be nearly independent of load.

TABLE 4. PERFORMANCE MEASURES OF THEORETICAL & SIMULATION RESULTS FOR LCL-T SPRC FED WITH RLE LOAD

Performance measures	Simulation Studies	Experimental Studies	Simulation Studies	Experimental Studies
	Without FLC		With FLC	
Load Voltage in Volts	99	95.3	99	97.5
Load Current in Amps	1.6	2.1	1.8	1.96
Settling Time in msec.	0.52	1.6	0.025	0.03
% Over Shoot	1.8	2.6	1	1.8
Steady state error	0.05	2	0.001	0.02

## 5.Conclusion

The Stability analysis of CLL-T and LCL-T SPRC has been module and simulated for estimating the performance for various load conditions. It has been found from the simulated results that the closed loop controller provides better control strategies. It is concluded that the FLC based LCL-T SPRC circuit provide load independent operation and better voltage regulation. A prototype 300 W, 100 kHz converter was designed, the experiment results are compared with the simulation results. The simulation results agree with the experimental results. This modeling is expected to provide.

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