CHAPTER 4

DESIGN OF SERIES PARALLEL RESONANT CONVERTER WITH PID CONTROLLER

4.1 INTRODUCTION

This chapter explains the closed loop control operation of the SPRC with PID controller. The design procedure of the SPRC is presented in section 4.3. The performance of the different resonant topologies such as CLL-T SPRC, LLC-T SPRC and LCL-T SPRC are simulated with PID controller and presented in section 4.4. The converter and controller performance has been analyzed and presented with variable load condition. Simulation results are presented to validate the design procedure.

4.2 PID CONTROLLER

PID controllers are probably the most commonly used controller structures in industry. They do, however, present some challenges to control and instrumentation engineers in the aspect of tuning of the gains required for stability and good transient performance. There are several prescriptive rules used in PID tuning. In the proposed system the Ziegler and Nichols method is used for tuning the gain value.
4.2.1 Controller Structure

A standard PID controller is also known as the three term controller, whose transfer function is generally written in the parallel form given by equation or the ideal form given by

\[ G(s) = K_p + \frac{K_i}{s} + K_d s \]  \hspace{1cm} (4.1)

\[ G(s) = K_p (1 + \frac{1}{T_i s} + T_d s) \]  \hspace{1cm} (4.2)

The proportional term in the controller generally helps in establishing system and improving closed loop response. It is overall control action proportional to the error signal through the all pass gain factor. The derivative term is often used when it is necessary to improve the closed loop response speed even further. The integral term-reducing steady state errors through low frequency compensation by an integrator. Conceptually the effect of the derivative term is to feed information on the rate of change of the measured variable into the controller action. The derivative term-improving transient response through compensation by a differentiator.

![Figure 4.1 General PID controller structure](image-url)
Controllers based on the PID approach are commonly used for DC–DC converter applications. Power converters have relatively low order dynamics that can be well controlled by the PID method. In fact, the PID controller is difficult to outperform for several reasons. The simulated structure of fuzzy controller in inverter and rectifier side is shown in figures 4.2 – 4.3 respectively.

Figure 4.2 Structure of the PID controller for inverter side

Figure 4.3 Structure of the PID controller for rectifier side
4.3 DESIGN PARAMETERS OF THE CONVERTER

For the design of SPRC [3], 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:

1. Power output \(= 300\text{W}\)
2. Minimum input voltage \(= 100\text{V}\)
3. Minimum output voltage \(= 100\text{V}\)
4. Maximum load current \(= 3\text{A}\)
5. Maximum overload current \(= 4\text{A}\)
6. Transformer Turns ratio \(= 1\)
7. Switching frequency \(f_s\) \(= 100\text{KHz}\)

The input rms voltage to the diode bridge
\[
V_{t2} = \frac{2\sqrt{2}}{\pi} V_o
\]

The input rms current at the input of the diode bridge
\[
\frac{V_{t2}}{I_d} = \frac{8 V_o}{\pi^2 I_o}
\]

Since switching frequency of LCL-T SPRC is equal to the resonant frequency
\[
f_s = \frac{1}{2\pi \sqrt{LC}}
\]
8. Series Inductance $L_1, L_2 = 39.18 \, \mu\text{H}$

9. Parallel Capacitance $(C) = 66 \, \text{nF}$

10. Load Inductance $(L_o) = 1\, \text{mH}$

11. Load Capacitance $(C_o) = 650\, \mu\text{F}$

The values used for all the elements are presented. These values have been obtained such that resonance for almost all power range (load-independent design) and also to limit the current and voltage peak values. To prove the wide load range operation and also to show that the fuzzy controller used is robust to parameter variations. The simulation and implementation are carried out for 300 W load power. The load used on the test is composed of a series connection of a resistor and a small inductor.

4.4 RESULT AND DISCUSSION

PID controller based SPRC are fed with resistive load are discussed for different resonant topologies such as CLL-T, LLC-T and LCL-T. The system is simulated with a switching frequency of 100 KHz. The resonant voltage, resonant current and output voltage with harmonic spectrum analysis are shown in figures for the different resonant topologies. The entire system is simulated for 10 milliseconds. It is observed that the PID controller based SPRC regulates the output voltage with a quick settling time compared to open loop system.

For a reference voltage of 100V the response is shown in figures 4.4-4.6. In the closed loop response by using PID controller, the overshoot and settling time is less compared to open loop and the response is oscillatory. The plots of resonant voltage, resonant current, output voltage across resistive load and measured THD values are shown in figures 4.4-4.6.
Figure 4.4  Resonant current and resonant voltage at 50 % of load for $V_r=100V$ (CLL-T SPRC with closed loop operation)

It can be seen that the resonant voltage and resonant current are shown in figure 4.5 operated with resonance frequency. The entire system is operated with half and full load condition. The half and full load condition the resonant voltage carry with harmonics. Due to the switching operation and conduction loss in the inverter bridge. It is clearly seen in the half and full load condition that the resonant current contains low harmonics and its presents a sinusoidal shape.

Figure 4.5  Resonant current and resonant voltage at 100 % of load for $V_r=100V$ (CLL-T SPRC with closed loop operation)
The output voltage with harmonic spectrum of the CLL-T SPRC with PID controller is shown in figure 4.6. Here the settling time 0.048 for 50% of load and 0.05 for 100% of load. The steady state error for 50% of load is 0.06 and 100% of load is 0.079.

![Graph](image1.png)

**Figure 4.6** Output voltage and Harmonic Spectrum at 50% and 100% of load (CLL-T SPRC with closed loop operation)

The resonant current and resonant voltage for different load condition was estimated for 50% and 100% respectively. The LLC-T SPRC is operated with the switching frequency of 100 KHz. The half and full load condition the resonant voltage and resonant current are probable in phase. The conduction loss and inverter switching loss is low compared to CLL-T SPRC.
Figure 4.7  Resonant current and resonant voltage at 50 % of load for $V_r=100\text{V}$ (LLC-T SPRC with closed loop operation)

It can be clearly seen in figure 4.7 at half load the inverter voltage is not seriously distorted, as the load current is not very high. In figure 4.8 the resonant voltage and resonant current is distorted at full load condition due to the effect of leakage inductance of the transformer. The frequency oscillation can also be viewed due to the resonance between the transformer leakage inductance and the capacitor of the MOSFET switches.
Figure 4.8  Resonant current and resonant voltage at 100 % of load for $V_r = 100V$ (LLC-T SPRC with closed loop operation)

It’s clearly seen from the figure 4.9 that the harmonics spectrum of the output voltage is high compared to the CLL-T SPRC due to the impedance matching in the inductance and the transformer inductance. The output voltage with harmonic spectrum is shown in figure 4.9. It can be seen that the harmonic content present in the half load is 11.25 % and full load is 10.23 %. Here the settling time is 0.048 for 50 % of load and 0.05 for 100 % of load, the steady state error for 50 % of load is 0.06 and 100 % of load is 0.079.
The resonant current and resonant voltage for 50% and 100% load condition has been estimated and shown in figures 4.10 - 4.12 respectively. The overshoot, settling time is found less compared to open loop and CLL-T SPRC, LLC-T SPRC with PID controller. It is seen that the inverter output is pure square wave without any harmonics and the frequency as of resonance frequency.
Figure 4.10  Resonant current and resonant voltage at 50 % of load for 
$V_t=100V$ (LCL-T SPRC with closed loop operation)

The LCL-T SPRC is operated with 50 % and 100 % load condition with resonance frequency, the resonant voltage and resonant current are shown in figure 4.10 and 4.11 respectively. The resonant current in half load and full load condition it is almost sinusoidal, because the operating frequency (about 100 KHz) is close to the resonance of the leakage inductance of the transformer and the resonant capacitor. The resonant voltage has some harmonic present due to the circulating current in the load.
Figure 4.12 shows the harmonic spectrum of the output voltage. It can be seen that the ripple content is minimum compared to the other resonant topologies. The Harmonic spectrum and DC component present in output voltage are very less compared to the open loop controller. It is observed that the settling time is 0.04 sec. for 50% and 0.059 sec. for 100% load. The steady state error for 50% load is 0.058 and 100% load is 0.06.
Figure 4.12  Output voltage and Harmonic Spectrum at 50% and 100% of load (LLC-T SPRC with closed loop operation)
4.5 CONCLUSION

In this chapter, series parallel resonant converter with closed loop operation has been investigated. The detailed operation of PID controller was studied and analyzed, design consideration was provided. The SPRC fed with resistive load operation was presented with PID controller. The dynamic characteristics of the converter were presented. It has been concluded that the PID controller was ineffective in eliminating the overshoot, rise time and high frequency noise suppression.