

ANALYSIS AND DESIGN OF EMBEDDED CONTROLLED PARALLEL RESONANT CONVERTER

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Abstract: Microcontroller based constant frequency controlled full bridge LC parallel resonant converter is presented in this paper for electrolyser application. An electrolyser is a part of renewable energy system which generates hydrogen from water electrolysis. The DC power required by the electrolyser system is supplied by the DC-DC converter. Owing to operation under constant frequency, the filter designs are simplified and utilization of magnetic components is improved. This converter has advantages like high power density, low EMI and reduced switching stresses. DC-DC converter system is simulated using MATLAB, Simulink. Detailed simulation results are presented. The simulation results are compared with the experimental results.

Keywords: DC-DC converter, resonant converter, filters, electrolyser, microcontroller, MATLAB, SIMULINK.

I. INTRODUCTION

Nowadays the energy conversion from renewable energy sources, such as wind turbine generators (WTGs) or photovoltaic (PV) arrays with suitable energy storage can play an important role in the development and operation of distributing energy source systems (stand alone or grid connected).

A renewable energy system (RES) converts the energy found in sunlight, wind, falling water, waves, geo thermal heat and Bio mass into the usable form, such as heat or electricity. Renewable energy storage in the form of hydrogen may overcome the inherent weakness of battery based energy storage systems like physical size, limited life span, and initial capital cost of the battery bank coupled with transportation, maintenance and battery disposal issues. During periods when the renewable resources exceed the load demand, hydrogen would be generated and stored through water electrolysis. For this purpose, electrolyser which breaks water into hydrogen and oxygen is used as an integral part of RES as shown in

Fig.1. During periods when the load demand exceeds the renewable resource input, a fuel cell operating on the stored hydrogen would provide the balance of power.

To ensure proper flow of power between the system elements, the available energy from different sources are coupled to a low voltage DC bus.

A direct connection of DC bus to the electrolyser is not suitable because it lacks the ability to control the power flow between the renewable input source and the electrolyser. Therefore, a power conditioning system, usually a DC-DC converter is required to couple the electrolyser to the system bus. High-frequency (HF) transformer isolated, HF switching dc-dc converters are suitable for this application due to their small size, light weight and reduced cost. To increase their efficiency and to further increase the switching frequency while reducing the size, cost and EMI problems, soft-switching techniques will be used in this paper. Resonant converters offer low switching losses due to zero voltage switching (ZVS)

making them popular for high frequency applications.

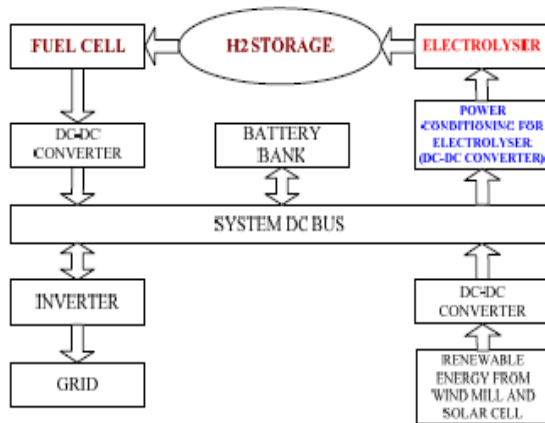


Fig.1. Renewable energy source system.

The emphasis, however, has mostly been on the analysis, design and optimization of resonant converters for constant output voltage power supplies. A number of high-frequency (HF) resonant converter configurations have been reported in the literature (Bhat, 1991a,b; Bhat, 1994; Steigerwald, 1984; Volperian and Cuk, 1982; Miller, 1976). Series resonant converter (SRC) is the simplest and most well documented configuration. SRCs have high efficiency from full load to part load. But the major disadvantage of the SRC is the difficulty in regulating the converter output voltage at light loads, i.e., they require very wide variation in switching frequency for load regulation. In an attempt to improve the performance of resonant converters, (PRC) higher order resonant converters have been proposed.

2. PAST EXPERIENCES

Analysis and design of LCL type resonant converter has been done by (Bhat, 1994). Steigerwald used high frequency resonant transistor for DC-DC converters (Steigerwald, 1984). A comparison of soft switched DC-DC converters for electrolyser application has been done by Gautam (Gautam, 2006). A series resonant converter for the same application has been done by Volperian (Volperian and Cuk, 1982). Miller used resonant switching power conversions during (Miller, 1976). Very fewer reports are available using DC-DC parallel resonant converter with C filter and LC filter for electrolyser application. An attempt has been made in the present work to implement DC-DC converter with LC filter using embedded microcontroller.

3. RESONANT CONVERTER

For many years, the Pulse Width Modulation (PWM) power supply technology has remained at relative

plateau in regard to the advances in performance, even though their power density (watts per cubic inch) and their frequency of operation remained low. The major heat producing losses within the PWM power supply are switching and conduction losses of the semiconductor power devices, arid core and resistive losses distributed. As the reduction in the size of power supplies become very important in toady's electronic systems and with the tangible improvement of the speed and the power handling of the power MOSFETS, the development of new converters technology began to evolve. The factor that limits the further reduction in the size of a switching power supply is its efficiency. Because resonant converters drastically reduce the switching losses within the supply, which is one of the top heat-generating losses, resonant converters are gaining wide interest in recent years. This removes 30 to 40 percent of the losses within a comparable PWM supply when operated at the same frequency. As a result, switching frequencies of 1 kHz to 15 MHz are now possible. Depending on the manner in which energy is transferred from the resonant tank to the output circuit, converters are classified as series or parallel converters. While the series uses the inductor current to transfer energy from the tank to the load, the parallel converter uses the voltage across the capacitor to transfer the energy. Parallel resonant converter topology presents several advantages over the other topologies if used separately. For instance, it minimizes the power switching loss since zero level current and voltage switching. In Section 4, a brief discussion of the analysis and design of the parallel resonant converter will be given. A set of nonlinear equations will be developed. Based on these equations solutions using the steepest decent method, for different frequencies and gains, will be found and a set of characteristic curves using these solutions will be presented. In Section 5, simulation results will be shown and the use of the characteristic curves in the design of the parallel resonant converter. In Section 6, the experimental results using microcontroller are presented in this paper.

4. ANALYSIS OF PARALLEL RESONANT DC-DC CONVERTER

The full bridge converter applies a square wave of voltage to a resonant network. The resonant network has the effect of filtering the higher harmonic voltages so that, essentially, a sine wave of current appears at the input to the resonant circuit (this is true over most of the load range of interest). This fact allows classical ac analysis techniques to be used. The analysis proceeds as follows. The fundamental component of the square wave input voltage is applied to the resonant network, and the resulting sine waves of current and voltage in the resonant circuit are computed using classical AC analysis. For a rectifier with an inductor output filter, the sine

wave voltage at the input to the rectifier is rectified, and the average value takes to arrive at the resulting dc output voltage. For a capacitive output filter, a square wave of voltage appears at the input to the rectifier while a sine wave of current is injected into the rectifier. For this case the fundamental component of the square wave voltage is used in the ac analysis.

60v DC is converted into high frequency AC using as inverter. The output of the inverter is filtered using LC filter. This is stepped down to 40v by using a step down transformer. Further this is rectified and filtered

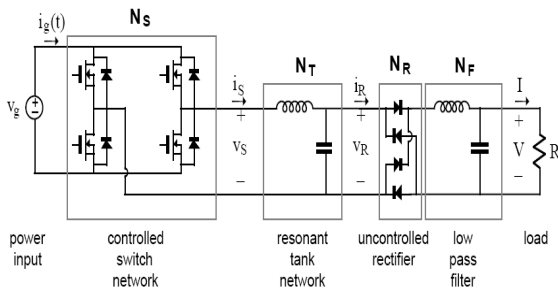


Fig.2. Parallel Resonant DC-DC Converter

using LC filter. The circuit of parallel resonant DC-DC converter is shown in the Fig. 2. Soft switching of the switches is done using LC circuit in the output of the inverter. The even harmonics in the output of the rectifier are filtered using LC filter. Driving pulses are applied to the MOSFET in such a way that the pulse width coincides with the resonant period. "Zero voltage switching" is a property that can be obtained in resonant converters whenever the tank presents a lagging (inductive) load to the switch network. This occurs for operation above resonance in the series

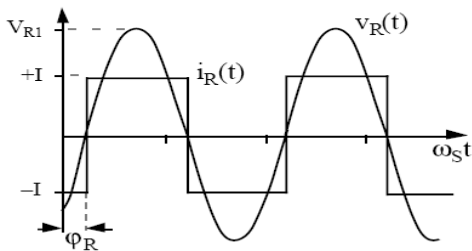


Fig.3. Parallel resonant converter waveforms $v_R(t)$ and $i_R(t)$

resonant converter, and it can lead to elimination of the switching loss which arises from the switch output capacitances. Likewise, "zero current switching" can be obtained when the tank presents a leading (capacitive) load to the switch network, as in the series resonant converter operation below resonance. In the parallel resonant converter, the output rectifiers are driven by the (nearly sinusoidal) tank capacitor voltage $v_R(t)$, and the diode rectifiers

switch when $v_R(t)$ passes through zero as in Fig. 3. The rectifier input current $i_R(t)$ is therefore a square wave of amplitude I, and it is in phase with the tank capacitor voltage $v_R(t)$.

The fundamental component of $i_R(t)$ is

$$i_{R1}(t) = \frac{4I}{\pi} \sin(2\pi f_s t - \phi_R)$$

Hence, the rectifier again presents an effective resistive load to the tank circuit, equal to

$$R_e = \frac{v_{R1}(t)}{i_{R1}(t)} = \frac{\pi V_{R1}}{4I}$$

The ac components of the rectified tank capacitor voltage $|v_R(t)|$ are removed by the output low pass filter. In steady state, the output voltage V is equal to the dc component of $|v_R(t)|$,

$$V = \frac{2}{T_s} \int_0^{T_s/2} V_{R1} |\sin(2\pi f_s t - \phi_R)| dt$$

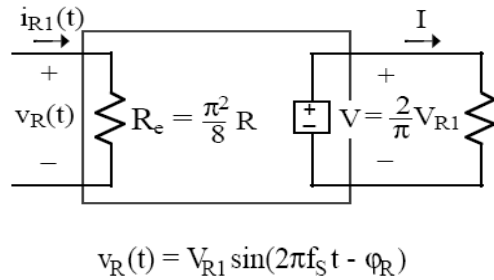


Fig.4. An equivalent circuit for the uncontrolled rectifier with inductive filter.

An equivalent circuit for the uncontrolled rectifier with inductive filter network is given in Fig. 4.

The effective resistance R_e has a different value. i.e

$$R_e = \frac{\pi^2}{8} R = 1.2337 R$$

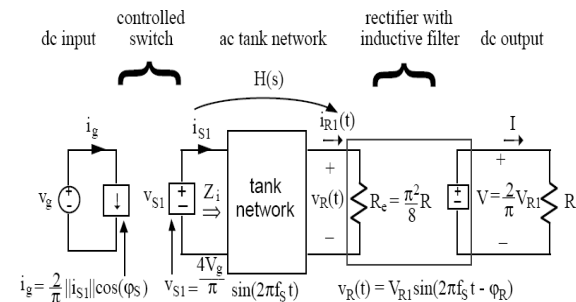


Fig.5. Equivalent circuit for the parallel resonant converter.

The converter dc conversion ratio is

$$M = \frac{V}{V_g} = \frac{8}{\pi^2} \| H(s) \|_{s=j2\pi f_s}$$

Where H(s) is the tank transfer function

$$H(s) = \frac{Z_0(s)}{sL}$$

$$Z_0(s) = sL \| \frac{1}{sC} \| R_e$$

5. SIMULATION RESULTS

The simulation circuit of resonant inverter with LC filter is developed using the blocks of simulink. The experimental results are obtained with the input voltage of 60V DC and converted to 40V. Scope1 is connected to display the driving pulses. Scope2 is connected to display the output voltage. DC-DC converter with shunt capacitor is shown in Fig. 6(a). Driving pulses given to the MOSFET's M1, M3 & M2, M4 are shown in Fig. 6(b). The output of the inverter is shown in Fig. 6(c). The output is nearly sinusoidal due to the C filter at the output of the inverter. DC output from the rectifier is shown in Fig. 6(d). DC-DC converter with LC filter at the output of the rectifier is shown in Fig. 7(a). DC output voltage with LC filter is shown in Fig. 7(c).

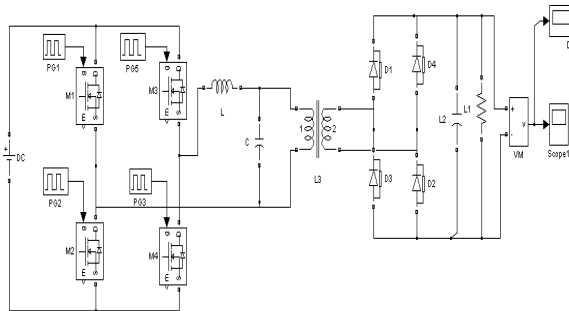


Fig.6(a). DC-DC Converter with C filter.

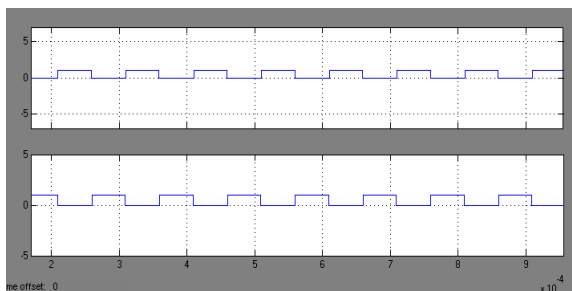


Fig.6(b). Driving Pulses

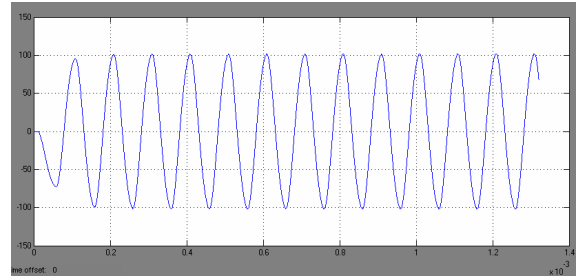


Fig.6(c). Inverter output with C filter

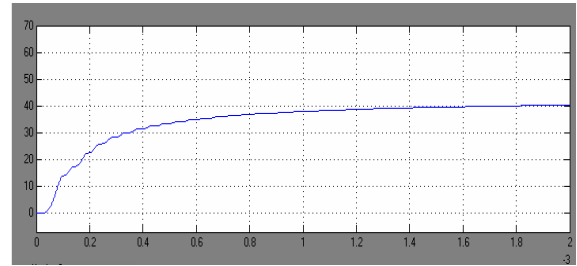


Fig.6(d). DC output voltage with C filter.

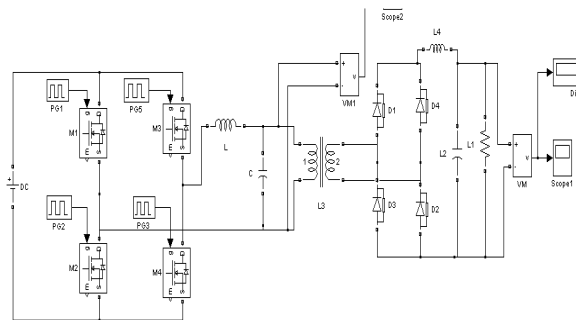


Fig.7(a). DC-DC converter with LC filter.

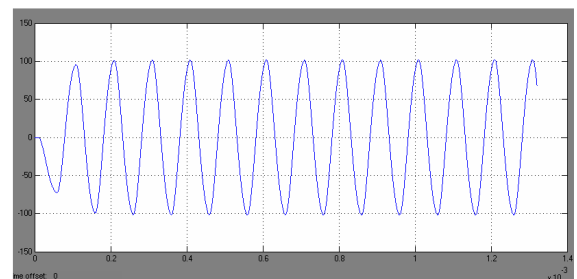


Fig. 7(b) Inverter output voltage with LC filter.

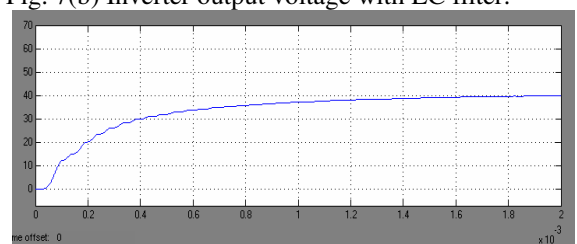


Fig.7(c). DC output voltage with LC filter.

6. EXPERIMENTAL RESULTS

The hardware for DC-DC converter is fabricated in the laboratory with the input DC voltage of 60V converted to 40V DC and it is tested. The hardware implementation details are shown in Fig.8a. The hardware consists of power circuit and microcontroller based control circuit. The pulses are generated using the microcontroller 89C2051. These pulses are amplified using the driver IC IR2110. The AC input voltage is shown in Fig.8b. The pulses generated by the microcontroller are shown in Fig.8c. The inverter output voltage is shown in Fig. 8d. The output of the inverter with LC filter is shown in Fig. 8e. This voltage is rectified using uncontrolled rectifier. The DC output voltage is shown in Fig. 8f. from the figures 6(c), 6(d), 8(e) and 8(f) it can be seen that the experimental results co inside with the simulation results.

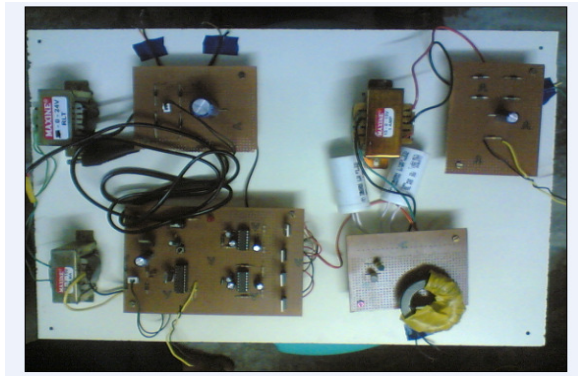


Fig.8(a).Embedded controlled full bridge LC resonant converter with an input DC supply of 60V.

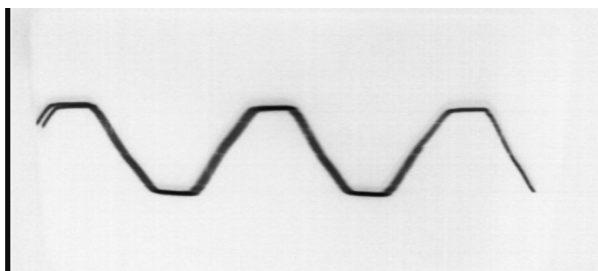


Fig.8(b). AC Input Voltage.

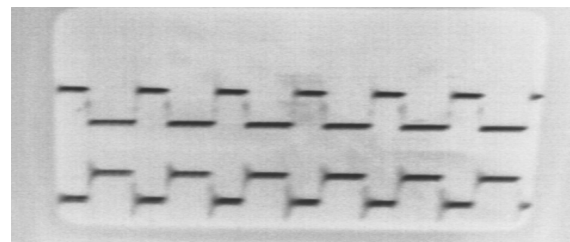


Fig.8(c). Driving Pulses

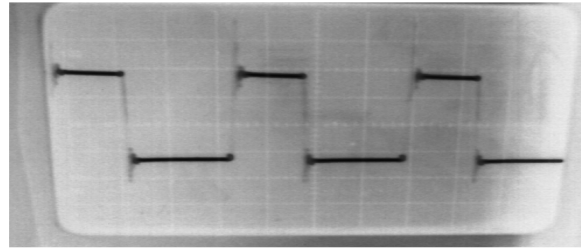


Fig.8(d). Inverter Output AC Voltage.
(Square Wave)

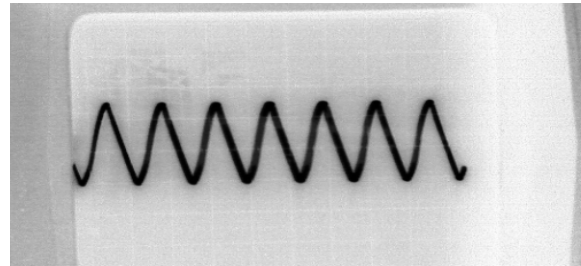


Fig.8(e). Inverter Output AC voltage after LC Filter
(sinusoidal)

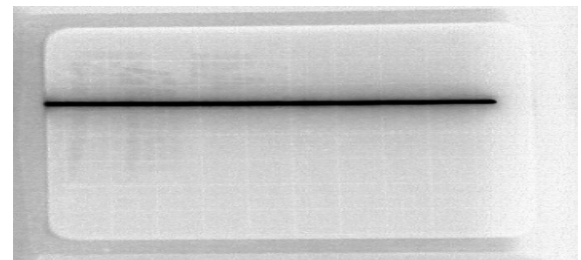


Fig.8(f). Constant DC Output Voltage (40V) at the load.

7. CONCLUSION

DC-DC converter system is simulated and tested in laboratory with the input voltage of 60V DC and converted to 40V DC. DC-DC converter system is simulated with 'C' filter, LC filter at the output and verified experimentally. The simulation results indicate that the output of the inverter is nearly sinusoidal. The output of rectifier is pure DC due to the presence of LC filter at the output. DC-DC converter with LC filter is a viable alternative to the existing converters, due to the advantages like reduced di/dt , low switching losses with high efficiency. In this paper parallel resonant converter is shown to exhibit voltage source behavior under variable load condition. MATLAB circuit model for the closed loop system is developed and it is successfully used for simulation studies. The experimental results closely agree with the simulation results.

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