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Low Cost Embedded Controlled Full Bridge LC Parallel Resonant Converter

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***Abstract*--- In this paper the converter requirements for an optimum control of an electrolyser linked with a DC bus are analyzed and discussed. An electrolyser is a part of renewable energy system which generates hydrogen from water electrolysis. The hydrogen generating device is part of a complex system constituted by a supplying photovoltaic plant, the grid and a fuel cell battery. The characterization in several operative conditions of an actual industrial electrolyser is carried out in order to design and optimize the DC/DC converter. A dedicated zero voltage switching DC/DC converter is presented and simulated inside the context of the distributed energy production and storage system. The proposed supplying converter gives a stable output voltage and high circuit efficiency in all the proposed simulated scenarios. The adopted DC/DC converter is realized in a full-bridge topology technique in order to achieve zero voltage switching for the power switches and to regulate the output voltage. This converter has advantages like high power density, low EMI and reduced switching stresses. The simulation results are verified with the experimental results.**

***Key words*--DC-DC converter, resonant converter, renewable energy sources., electrolyser, 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) In the recent years the technology development of the fuel cells energy storage systems allowed the use of the fuel cell as an alternative to the commonly used battery storage systems. In distributed energy source applications electrolytic hydrogen offers a promising alternative for long-term energy storage of renewable energy. In the present paper a distributed energy source is described and discussed focusing on the interaction among the several parts connected to the electrical DC bus. A key role inside this technical environment is played by the machines used for the hydrogen production. In modern complex networks they are mainly used for the production of energy supplied by the grid itself or other renewable energy systems, such as PV plants. The main aim of this electrical system is the hydrogen storage devoted to the suitable load supplying in order to obtain an optimum load profile in case of domestic consumers. The energy is supplied to the electrolyser or the storage system according to the load profile. The stored hydrogen is fed to a fuel cell to produce electricity. The main target of the analysis is the evaluation of a DC-DC converter topology that supplies the electrolyser in order to obtain the optimization of the converter efficiency. The converter switches which have been used are super junction MOSFETs with reduced forward resistance in the conduction mode and improved dynamic characteristics in the switching transients. The converter strategy control allows a zero voltage transient on the power switches of the full-bridge inverter. Several simulation runs have been carried out in order to better understand the impact of the DC-DC converter chosen in the system application. Finally the experimental converter prototype are presented and discussed. In order to understand the behavior of the electrolyser system and for the suitable design of the supply DC-DC converter, a characterization on an actual electrolyser has been carried out. The electrolyser is connected to the DC bus through a DC-DC power converter. The output is hydrogen feeding a suitable storage tank as shown in Fig. 1.

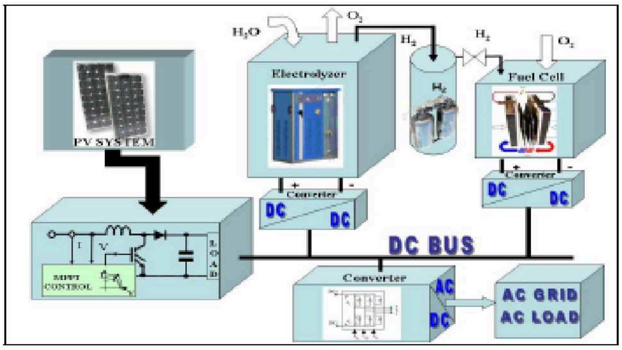

Fig. 1 Distributing Energy Source System

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. The emphasis, however, has mostly been on the analysis, design and optimization of resonant converters for constant output voltage power supplies.

II. 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 (1984). A Comparison of soft switched DC-DC converters for electrolyser application has been done by Gowtham (2006). A series resonant converter for the same application has been done by Volprian (1982). Miller used resonant switching power conversions during (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.

III. ANALYSIS OF FULL BRIDGE PARALLEL RESONANT DC-DC CONVERTER

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 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.

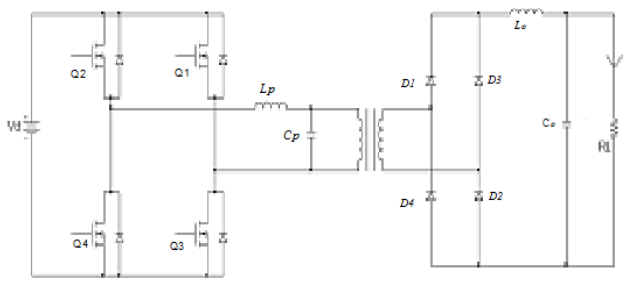

Fig. 2 Parallel Resonant DC-DC Converter

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.

A. Q2 ON, Q3 ON; Q1 OFF, Q4 OFF

As shown in Fig.2, current flows through Q3, resonant inductance, the transformer primary and Q2 back to the input.

The voltage on the primary is shown in equation 1,

$$V_P = V_{DC} - V_{Q2,on} - V_{Q3,on} - V_{Lp} = V_{DC} - 2V_{Q,on} - V_{Lp} \quad (1)$$

The magnetizing current $i_{M(t)}$ is

$$i_{M(t)} = V_P / L_P \,.\, t = \frac{V_{DC} - 2V_{Q,on} - V_{Lp}}{L_P}\, t \quad (2)$$

As for the primary winding, the dot end of the secondary winding is more positive that the non-dot ends. This implies that diode D1 & D2 is conducting while diode D3 & D4 is not conducting. The secondary voltage can be computed as shown in equation 3.

$$V_S = (N_S/N_P).V_P = N_S/N_P(V_{DC} - 2V_{Q,on} - V_{Lp}) \quad (3)$$

Equation 4 shows the current flowing into the inductor.

$$i_{Lp}(t) = i_{Lp}(0) + \frac{V_{DC} - 2V_{Q,on} - V_{Lp}}{L_p}\, t \quad (4)$$

The voltage on the output capacitor Co, shown in Equation 5.

$$V_{Lo} = (N_S/N_P).\, V_p - 2V_{D,on} - V_O = (N_S/N_P)\,.\, V_{DC} - V_O > 0$$
$$V_O = N_S/N_P\,(V_{DC} - 2V_{Q,on} - V_{Lp}) - 2V_{D,on} - V_{Lo} \quad (5)$$

B. Q1 ON, Q4 ON; Q2 OFF, Q3 OFF

As shown in Fig. 2, current flows through Q1, the transformer, resonant inductor and Q4 back to the input. The dot end of the transformer is now more negative than the non-dot end.

The primary voltage is shown in Equation 6.

$$VP = -VDC + VQ1,on + VQ4,on + VLp$$
$$= -VDC + 2VQ,on + VLp \quad (6)$$

$$i_{M(t)} = V_P / L_P \,.\, t = \frac{-V_{DC} + 2V_{Q,on} + V_{Lp}}{L_P}\, t \quad (7)$$

In this instance, as at the primary, the dot ends are more negative than the non-dot ends, which results in Equation 8.

$$V_S = (N_S / N_P)\,.V_P = -N_S / N_P\,(V_{DC} - 2V_{Q,on} - V_{Lp}) \quad (8)$$

The output inductor voltage is shown in Equation 9.

$$V_{Lo} = N_S / N_P\,(V_{DC} - 2V_{Q,on} - V_{Lp})V_{D3,on} - V_{D4,on} - V_O$$
$$V_{Lo} = V_S - 2V_{D,on} - V_O \quad (9)$$

The current flowing through the output inductorit is shown in Equation 10.

$$i_{Lo(t)} = i_{Lo(0)} + \frac{(N_S / N_P) \,.\, V_{DC} - V_O}{L_o} \; t \qquad (10)$$

The voltage on the output capacitor CO is shown in Equation 11.

$$V_O = [N_S/N_P(V_{DC} - 2V_{Q,on} - V_{Lp}) - 2V_{Don} - V_{Lo}] \qquad (11)$$

The output voltage can be obtained across the load is

$$V_O = [N_S/N_P\,(V_{DC} - 2V_{Q\square on} - V_{Lp}) - 2V_{D,on} - V_{Lo}]\, D \qquad (12)$$

where $D = T_{ON}/T$.

The output power of the converter is

$$P_{OUT} = \eta \,.\, P_{IN} = \eta \,.\, V_{DC,min} \,.\, I_{IN,\,av} \,.\delta \qquad (13)$$

where $I_{IN,av}$ is the average input current and $\delta = 0.8$

$$I_{IN,av} = \frac{P_{OUT}}{V_{DC,min}\,\delta} \qquad (14)$$

IV. SIMULATION RESULTS

The simulation circuit of resonant inverter with LC filter is developed using the blocks of simulink. 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. 3(a). Driving pulses given to the MOSFET's M1,M3 & M2,M4 are shown in Fig. 3(b). The output of the inverter is shown in Fig. 3(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. 3(d). DC-DC converter with LC filter at the output of the rectifier is shown in Fig. 4(a). DC output voltage with LC filter is shown in Fig. 4(c).

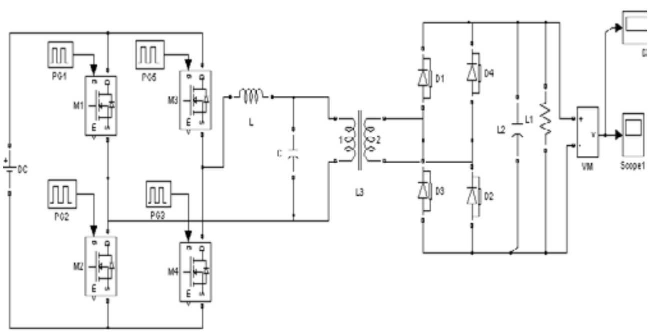

Fig. 3(a) DC-DC converter with C filter circuit diagram.

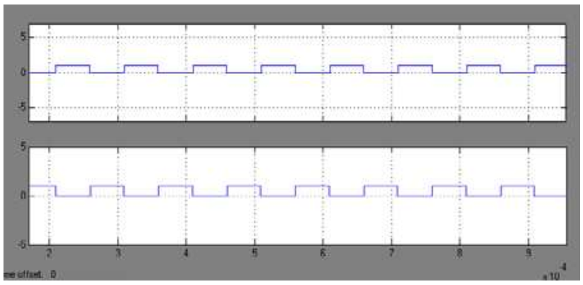

Fig. 3(b) Driving Pulses

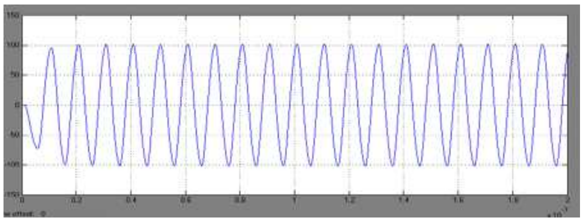

Fig. 3(c) Inverter output with C filter

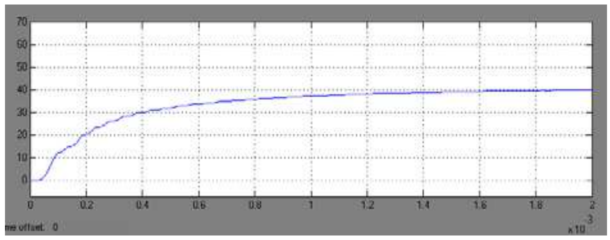

Fig. 3(d) DC output voltage with C filter

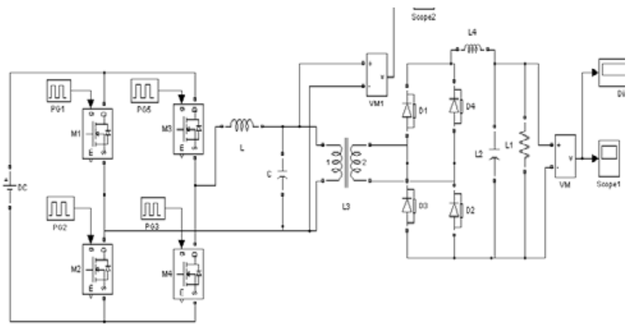

Fig. 4(a) DC-DC converter with LC filter circuit diagram.

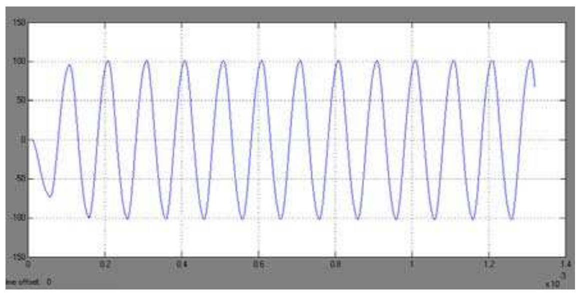

Fig. 4(b) Inverter output. (LC filter).

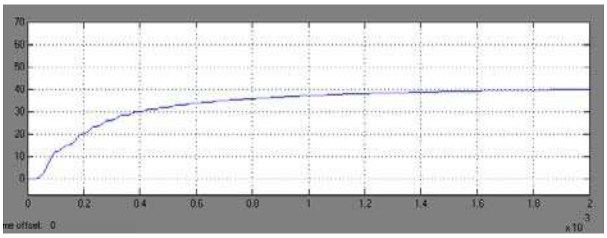

Fig. 4(c) DC output voltage with LC filter.

V. EXPERIMENTAL RESULTS

The hardware for DC-DC converter is fabricated in the laboratory and it is tested. The modulation of the driving signals for the converter device is used as a control parameter to maintain the supply voltage value at the request value of 40v. It is clearly shown in figures that the power losses in the occurrence of the turn on switching are maintained very low by means of the resonant operation. The hardware implementation details are shown in Fig. 5(a). The pulses are generated using the ųC 89C2051. These pulses are amplified using the driver IC IR2110. From Figs. 3(c), 3(d), 5(a) and 5(f), it can be observed that the experimental results co inside with the simulation results.

Fig. 5(a) Embedded controlled full bridge LC resonant converter

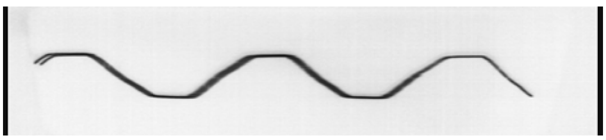

Fig. 5(b) AC Input Voltage

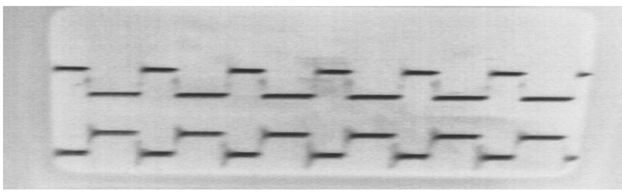

Fig. 5(c) Driving Pulses

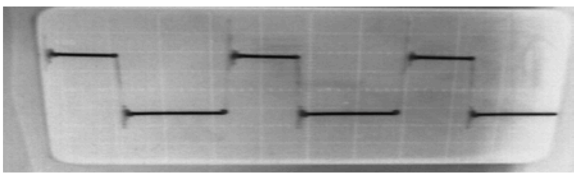

Fig. 5(d) Inverter Output Voltage

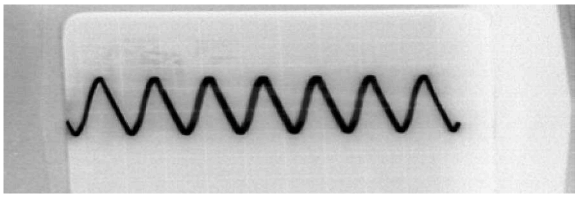

Fig. 5(d) Output after LC Filter

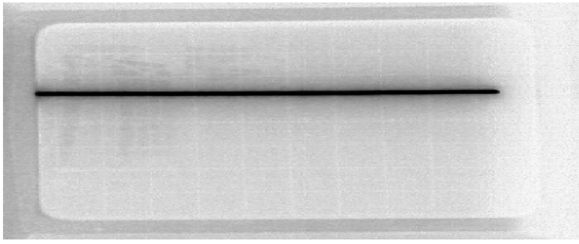

Fig. 5(d) DC Output Voltage

VI. CONCLUSION

DC-DC converter system is simulated and tested in laboratory. 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. The converter maximizes the efficiency through the zero voltage switching and the use of super-junction MOSFET as switching devices with high dynamic characteristics and low direct voltage drop. The experimental results closely agree with the simulation results.

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