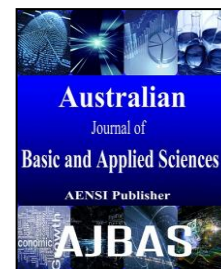




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Single Switch Resonant Power Converter for Renewable Energy Generation Applications

¹N. Fouzia Fathima and ²Dr. I. Gnanambal

¹PG Scholar, Department of Electrical and Electronics Engineering, Engineering, Government College of Engineering, Salem-11, Tamil Nadu, India.

²HOD/ Associate Professor, Department of Electrical and Electronics Government College of Engineering, Salem-11, Tamil Nadu, India.

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ABSTRACT

This paper presents a single-switch resonant power converter that can be used in renewable energy generation applications. It combines an energy blocking diode with a single-switch resonant converter under soft switching conditions. The output stage consists of an energy-blocking diode and filter. The converter consists of only one active power switch for power energy conversion. Thus, the cost of active power switches and control circuits is considerably reduced. This switch uses pulse width modulation technique at a fixed switching frequency and a constant duty cycle. The discontinuous conduction mode in the resonant converter ensures ZCS operation. For the chosen circuit parameters, ZVS operation of the active power switch has been applied. Thus, these soft-switching technique have resulted in high efficiency. Simulation results thus obtained provide a satisfactory performance of the proposed converter, which is more suitable for the energy conversion operation in renewable energy generation domain.

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INTRODUCTION

In this modern world where fossil fuels are being used at an increased rate, there is a risk of these sources getting exhausted in the near future. But the use of fossil fuel has led to greenhouse gas emissions and environmental pollution. Also, the global demand for electric energy has continuously increased over the last few decades. So energy and the environment have become serious concerns in today's world. Since these conventional energy sources are depleting at a fast pace, the focus has now shifted to renewable energies (RES).

Renewable energy sources have drawn more and more attention in recent years. Photovoltaic (PV) sources and wind farms are predicted to become the biggest contributors to electricity generation among all renewable energy generation candidates by 2040. PV power generation systems are the most promising future sources of energy. It is because of their advantages, such as the absence of a need for fuel and the associated cost saving, low maintenance, and lack of noise. The PV module can be installed on rooftops thus effectively eliminating transmission line losses. The energy collected on PV arrays is

being utilized as the source of a renewable energy for reduction of fossil fuel energy.

The output from the PV array panel is direct current (d.c) output. It is directly applied to D.C loads and converted to A.C. using DC-AC converters/inverters in case of A.C. loads. Since the output from the solar panel varies all the time, a DC to DC converter (boost type) that converts the unregulated DC input to a controlled DC output with desired voltage level is used. Also, if the dc output is connected with a battery energy storage system (BESS), the output dc voltage of the source of the RES will be marked to that of the voltage of BESS. So the renewable energy production system cannot operate optimally at all time. So, a dc/dc interface must be installed between the renewable energy generation system and the BESS to ensure that the renewable energy generation system always operates at its optimum operating points to get maximum efficiency. Various configurations of DC-DC converters are available each having its own advantage and disadvantage.

Literature survey shows that traditional ZCS converters operate with constant on-time control. They must operate with a wide range of switching

Corresponding Author: N. Fouzia Fathima, PG Scholar, Department of Electrical and Electronics Engineering, Engineering, Government College of Engineering, Salem-11, Tamil Nadu, India.
E-mail: nfouziafathima@gmail.com

frequencies when the ranges of the input source and load are wide, making the filter circuit design difficult to optimize. The simplest method for controlling power semiconductor switches is pulse width modulation (Rahimi, A.M. and A. Emadi, 2010; Liu, F., 2010; Li, W., 2012). The traditional ZVS scheme eliminates capacitive turn-on losses and decreases the turn-off switching losses by reducing the rate of increase in voltage, reducing the overlap between the switch voltage and the switch current. The ZVS and ZCS schemes have been under study because of their efficient operation (Cuzner, R.M., 2007; Ilic, M. and D. Maksimovic, 2007; da Silva Martins, M.L., 2006). This work develops a single-switch highly efficient converter with ZVS topology based on the traditional ZVS concept and an isolated circuit to trigger the active power switch for use in renewable energy generation applications (Emrani, A., 2012; Kwon, J.M., 2009; Park, K.B., 2009).

Resonant Power converter:

Based on the voltage or current at switching time using PWM, the converters are classified as hard switched and resonant/soft switched converters. In hard switched converters, transistors switch while full voltage and full current are flowing through it. This increases the losses and reduces the efficiency. In resonant converters using soft switching, an LC circuit controls the voltage across the transistor as well as the current through it so that the transistor switches when either the voltage or the current is zero.

Most soft-switching converters rely on the process of resonance. Resonant switching techniques reduce the switching losses to practically zero; the switching frequency then maybe increased to higher value of kHz to achieve higher power density. Such converters are classified as "soft-switching converters". The distinguishing feature of the soft switched converters is that they switch ON and OFF at zero current and/or zero voltage. The switching techniques in the resonant converter use ZVS and/or ZCS. In ZCS, the device turns on with zero current and turns off after the current drops to zero. In ZVS, the switch turns off at zero voltage and turns on after the device voltage drops to zero.

Resonant converters are being extensively utilized in the application of renewable energy generation systems. The basic requirements of resonant converters are their high efficiency and small size. A high switching frequency is needed to achieve small size. But, the switching loss increases with the switching frequency, reducing the efficiency of the resonant converters. With higher frequencies, are the problems of greater stress in the switching devices, greater susceptibility to parasitic capacitance and leakage inductance and increased EMI and RFI. A resonant mode system offers the potential for achieving the benefits while sidestepping many of

the disadvantages of higher frequencies. Resonant converters also provide improved diode recovery.

As a consequence, the resonant converter using soft-switching technique seems to be more suitable for high power applications. Therefore, a new soft switching PWM boost DC-DC converter with a single switched resonant converter is proposed.

Proposed Technique:

This paper develops single switch highly efficient converter with ZVS topology based on the traditional ZVS concept for renewable energy generation applications. The important features of the proposed system include a simple circuit structure, ease of control, soft switching for active power devices, low switching losses, and high energy conversion efficiency. This single-switch high-efficiency converter with ZVS topology can be considered to be an extension of the traditional ZVS power converter. It utilizes a capacitor across the active power switch in the single-switch power converter to generate a freewheeling stage with a traditional ZVS power converter. This enables the converter to operate with a constant frequency and a markedly much reduced circulating energy. The application of this power electronic converter depends on the effectiveness of its structure in minimizing switching losses in the energy transformation interval. Unlike the traditional ZVS converter, this paper proposes a single-switch resonant power converter that has only a single-ended structure, which must have an isolated circuit to trigger the active power switch.

The use of a single switch resonant power converter in the dc/dc energy conversion stage in a renewable energy generation system provides many advantages, such as low cost, a low number of components, and high power density. These characteristics, as well as the fact that the ZVS resonant power converter has only a single active power switch, cause the novel power converter to have a very simple structure, low switching losses, a small volume, and a low weight. In addition, since the commutations in the active power switch of the resonant power converter are performed at zero voltage, the switching losses are very low, resulting in very high efficiency.

The circuit diagram of the proposed converter is shown in Fig.1. It comprises of a choke inductor L_m , a metal-oxide-semiconductor field-effect transistor (MOSFET) that operates as a power switch S , a shunt capacitor C , a resonant inductor L_s , an energy-blocking diode D , and a filter capacitor C_o . The capacitor C_o and the load resistance R together form a first-order low-pass output filter. It reduces the ripple voltage below a specified level. The MOSFET is a favored device because its body diode can be used as an antiparallel diode DE for a bi-directional power switch. Notably, the shunt capacitance

Cincludes the power switch parasitic capacitance and any other stray capacitances (such as the winding capacitance of the choke L_m). Careful design of the circuit parameters guarantees that ZVS switches the power switch S and ZCS switches the energy-blocking diode D , optimizing the operation of the converter.

The various assumptions taken into account for the operation include the ideal condition of the switching elements, negligible equivalent series resistance and stray capacitance of the capacitor,

linear and time-invariant characteristics of the passive components and large filter capacitance at the output.

Converter Operation:

In order to explain the working of the proposed converter, one switching cycle is divided into six modes, which are described along with their corresponding simplified equivalent circuits as follows:

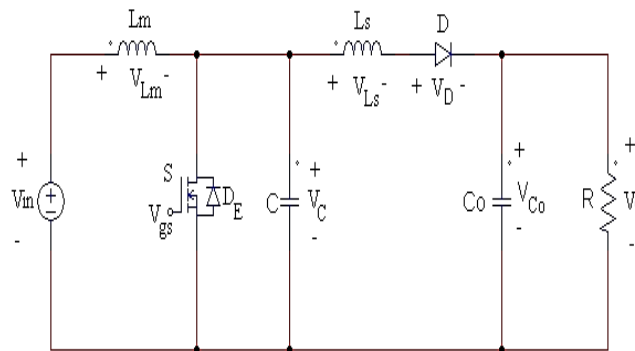


Fig. 1: Basic circuit diagram of the proposed single switch resonant power converter.

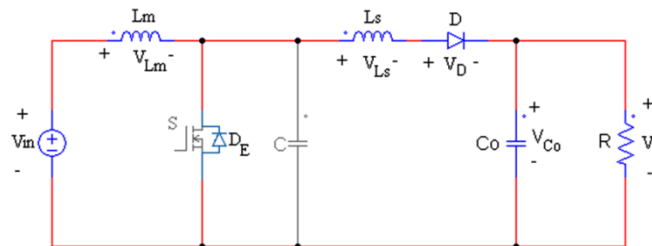


Fig. 2: Equivalent circuit of Mode I.

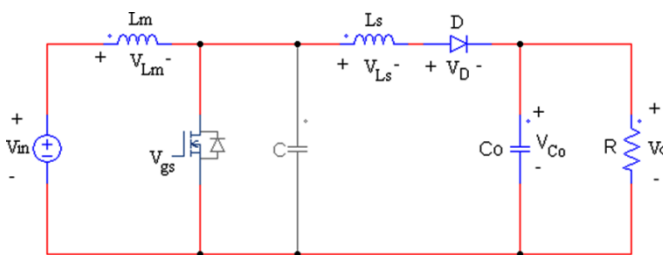


Fig. 3: Equivalent circuit of Mode II.

Mode I:

Prior to Mode I, the active power switch S is off. The resonant tank current i_{L_s} is positive and exceeds the dc input current i_{L_m} . The power switch must be turned on only at zero voltage. Otherwise, the energy stored in the capacitor C will be dissipated in the switch S . To prevent this the antiparallel diode D_E must conduct before the power switch is turned on. The capacitor current i_C is negative, it flows through capacitor C . When the capacitor voltage V_C falls to zero, a turn-on signal is applied to the gate of the active power switch S . Therefore, the active power switch S turns on under ZCS and ZVS

conditions. At the beginning of this mode, the antiparallel diode D_E conducts because the difference between currents $i_{L_m} - i_{L_s}$ is negative. In this mode, the energy blocking diode D is turned on because the resonant tank current i_{L_s} is positive. Fig. 2 represents the equivalent circuit of this mode. The initial condition of the inductor current i_{L_s} is I_{Ls0} . Then, the instantaneous inductor current and the voltage across capacitor C can be evaluated using

$$i_L(t) = -\frac{I_{Ls0}R}{L}(t-t_0) + I_{Ls0} \tag{1}$$

$$V_C(t) = 0 \tag{2}$$

This mode ends as soon as the antiparallel diode D_E is reverse biased by a positive current $i_{Lm} - i_{Ls}$.

Mode II:

In this period, the switch S remains in the ON state. Fig. 3 shows the equivalent circuit. The line voltage is applied to the choke inductor L_m , and i_{Lm} increases continuously. In this mode, the current $i_L - i_{Ls}$ naturally commutates from the antiparallel diode D_E to the active power switch S . Accordingly, the voltage across the capacitor C is clamped at zero. The resonant current i_{Ls} passes through the energy blocking diode D . During this

interval, the inductor current i_{Ls} is expressed as follows, where I_{Ls1} is the initial current in the inductor i_{Ls} :

$$i_{Ls}(t) = -\frac{i_0 R}{L}(t - t_0) + I_{Ls1}^+ \tag{3}$$

$$I_{Ls1}^+ = -\frac{i_0 R}{L}(t_1 - t_0) + I_{Ls0}^+ \tag{4}$$

The following equation gives the voltage $V_c(t)$ across the resonant capacitor C :

$$V_c(t) = 0 \tag{5}$$

The circuit operation enters Mode III when the inductor current I_{Ls} falls to zero.

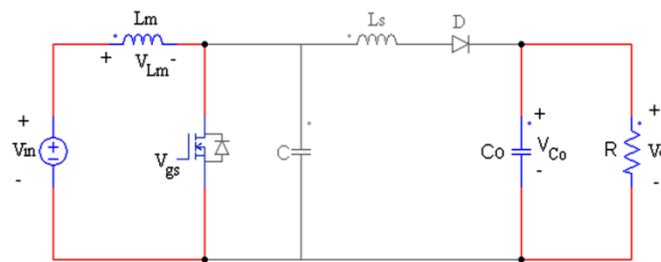


Fig. 4: Equivalent circuit of Mode III.

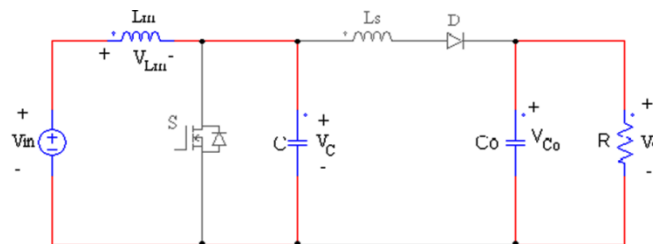


Fig. 5: Equivalent circuit of Mode IV.

Mode III:

In Mode III, the active power switch S remains in the ON state, and the input dc current i_{Lm} continuously increases. The choke inductor current i_{Lm} flows through the active power switch S . The inductor current i_{Ls} falls until it reaches zero and is prevented from going negative by the energy blocking diode D . Notably, the dc input source is not connected directly to the output load in the novel single-switch converter. Energy is stored in the choke inductor when the active power switch is turned on and is transferred to the output load when the active power switch is turned off. Fig.4 displays the equivalent circuit of this mode. Accordingly, the inductor current $i_{Ls}(t)$ and the capacitor voltage $v_c(t)$ of the converter circuit are as given in

$$i_{Ls}(t) = 0 \tag{6}$$

$$V_c(t) = 0 \tag{7}$$

This mode is exited at the time when the power switch S is turned off.

Mode IV:

At the beginning of Mode IV, the active power switch S is switched off. The capacitor current I_C becomes i_{Lm} . Then, the capacitor voltage V_C rises

from zero to a finite positive value. For ZVS operation, S is switched off at zero voltage, and the capacitor voltage V_C increases linearly from zero at a rate that is proportional to i_{Lm} . The capacitor current i_c flows through capacitor C to charge C , transferring the energy from the dc input source to capacitor C . During this mode, the output power of load resistor R is supplied by the output capacitor C_0 . Fig.5.2 reveals that the active power switch S is turned off under the ZVS condition. Fig.5 presents the equivalent circuit.

The following equation gives the inductor current $I_{Ls}(t)$ of the single-switch power converter circuit:

$$I_{Ls}(t) = 0 \tag{8}$$

The following equation gives the voltage $V_c(t)$ of the capacitor C :

$$V_c(t) = \frac{i_{Lm}}{C}(t - t_3) \tag{9}$$

This mode ends when the energy blocking diode D gets forward biased i.e., ($V_C > V_O$). Then, the circuit operation enters Mode V.

Mode V:

In Mode V, the active power switch S remains in the OFF state. The current $i_{Ls}(t)$ is positive, and the energy blocking diode D is turned on, yielding a resonant stage between inductor L_s and capacitor C. In this interval, the capacitor current i_C is still positive. Hence, the capacitor voltage V_C continues to increase to its peak value. Fig.6 presents the equivalent circuit.

The inductor current $i_{Ls}(t)$ is given as

$$i_{Ls}(t) = I_{Lm}[1 - \cos\omega_o(t - t_4)] - \frac{V_{Cs}^+}{Z_o} \sin\omega_o(t - t_4) + \frac{I_o R}{Z_o} \sin\omega_o(t - t_4) \quad (10)$$

where the angular resonance frequency is $\omega_o = 2\pi f_o = 1/\sqrt{L_s C}$ and the characteristic impedance $Z_o = \sqrt{L_s/C}$, respectively. The following equation gives the voltage $V_C(t)$ of the resonant capacitor:

$$V_C(t) = Z_o I_{Lm} \sin\omega_o(t - t_4) + V_{Cs}^+ \cos\omega_o(t - t_4) + I_o R [1 - \cos\omega_o(t - t_4)] \quad (11)$$

Mode V ends when capacitor current i_C resonates to zero at ωt_5 , and operating Mode VI then begins.

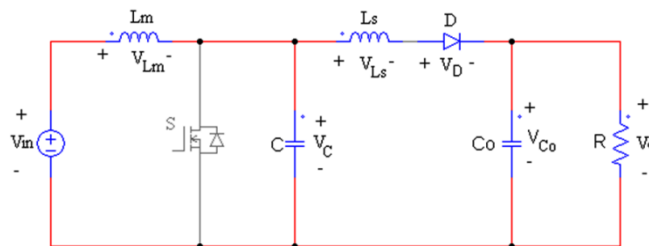


Fig. 6: Equivalent circuit of Mode V.

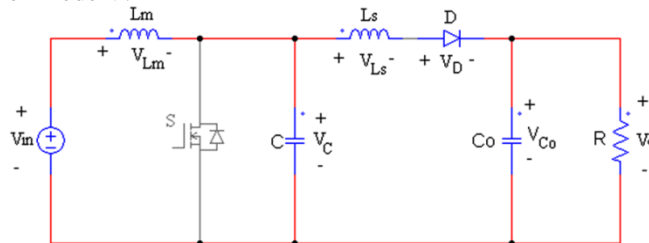


Fig. 7: Equivalent circuit of Mode VI.

Mode VI:

This cycle begins at ωt_5 when capacitor voltage V_C resonates from negative to zero. The active power switch S is turned on when $\omega t = 2\pi$ to eliminate switching losses. Fig.7 illustrates the equivalent circuit.

Before the cycle of the resonant inductor current i_{Ls} oscillation comes to an end, the active power switch S is kept off condition, constraining the positive current to flow continuously through the energy blocking diode D. In addition to the active power switch, the energy blocking diode in the proposed converter is also commutated under soft switching. This feature makes the novel single-switch resonant power converter topology particularly useful for high-efficiency energy conversion applications.

When the driving signal V_{gs} again excites the active power switch S, mode VI ends, and the operation returns to Mode I in the following cycle.

Simulation Results:

'Simulation' Is The Representation Of A System In Its Realistic Form. Before Implementing A New Idea, By Simulation, One Can See The Effect Of Various Parameters Or Components On The Output Accordingly Change Them To Get A Desired Output. Psim Denotes Power Simulation.

Psim Is Simulation Software Specifically Designed For The Analysis And Design Of Power Electronics And Control Circuits. It Provides A Powerful Simulation And Design Environment For Power Supplies, Analog/Digital Control And Electric Motor Drives. Simview Is The Waveform Display And Post-Processing Program For Psim. It Provides A Powerful Environment To Display And Analyze Simulation Results. Simulation Results Were Obtained For The Proposed Single Switch Resonant Power Converter For Renewable Energy Generation Applications Using Psim Software. Fig. 8 Shows The Simulation Circuit Diagram. The Proposed Converter Was Simulated Based On The Following Specifications:

Output Voltage: $V_o = 18$ Volts

Input Voltage: $V_{IN} = 15$ Volts

Output Power: $P_o = 32.4$ W

Switching Frequency: $f_s = 88$ kHz

Duty cycle: $k = 0.357$

The following components were used to implement the simulation of the proposed converter

Load Resistor: $R = 10$ ohm

Resonant Inductor $L_r = 19$ μ H

Resonant Capacitor $C_r = 0.18$ μ F

Choke inductor $L_m = 8$ mH

Output Capacitor $C_o = 220$ μ F

The Fig. 14 gives the output voltage and current waveforms of the load, which are smooth dc voltage and current waveforms, respectively. The output voltage equals 18V, which can be used to drive light-emitting diode lighting systems. The energy conversion efficiency of the proposed novel single-switch resonant

power converter is as high as 97.3% at output power $P_o = 32.4$ W. In addition, the proposed novel single-switch resonant power converter has great potential for use in renewable energy generation applications.

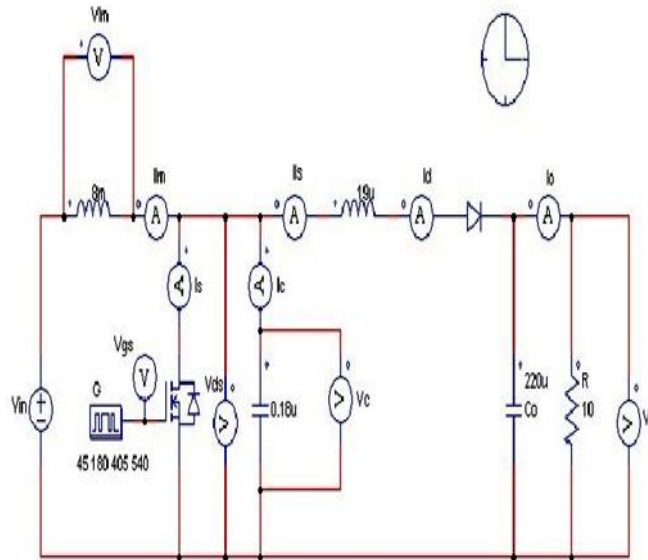


Fig. 8: Simulation circuit of proposed converter.

The circuit is simulated at 18Vdc input by using PSIM Software. The Fig. 9 shows the waveforms of active power switch S where Vgs represents the trigger signal on active power switch S, and Vds represents the voltage across the active power switch S. From Fig. 10 it is evident that the active power switch is operated on ZVS. Thereby switching losses are greatly reduced. ZVS is achieved by resonant tank L_s and C which are very small in values. Thereby circuit weight is less and achieves high efficiency.

waveform V_c and the current waveform I_c of the resonant capacitor, respectively.

Conclusion:

In this paper, an integrated system of energy blocking diode and a single switch resonant power converter has been developed. It can be used in solar energy generation systems. It differs from other resonant power converters, which require numerous components in the structure. The proposed converter is very simple and cheap. The advantages include reduction in switching losses and increase in efficiency. The proposed converter has been simulated at high frequency with a resistive load. The simulation results obtained show high efficiency of about 97.3% that reveals the effectiveness of the proposed converter.

Fig. 11 displays the voltage and current waveforms of the choke inductance L_m at the input terminal. The choke inductance L_m is sufficiently large that the input current i_{L_m} is almost constant. The Fig. 12 sketches the voltage

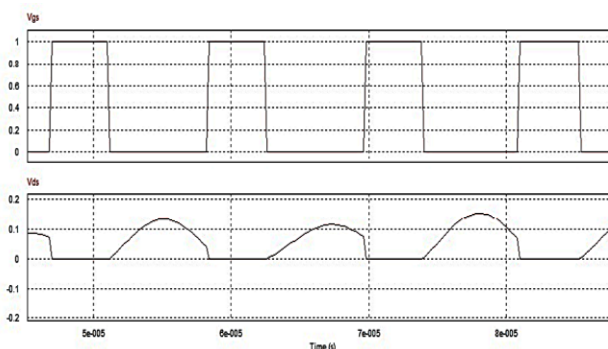


Fig. 9: Trigger signal and voltage waveforms of the active power switch.

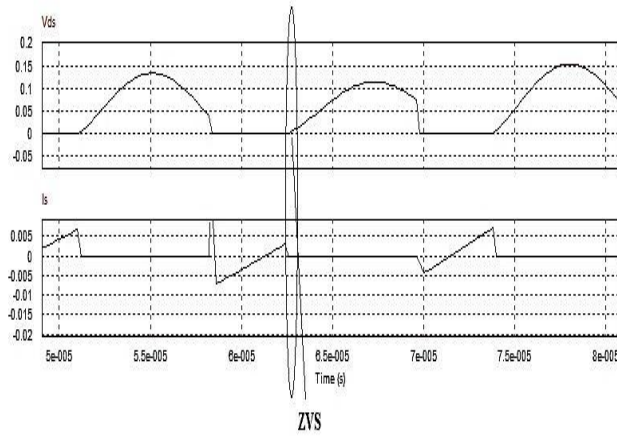


Fig. 10: Voltage and current waveforms of the active power switch.

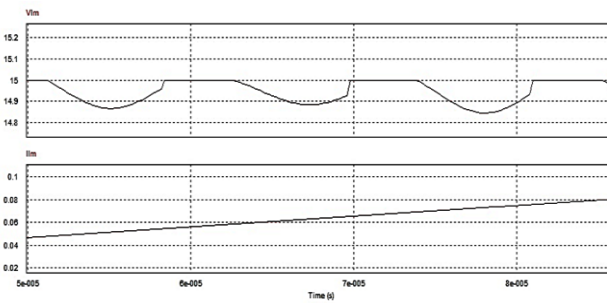


Fig. 11: Voltage and current waveforms of the choke inductor.

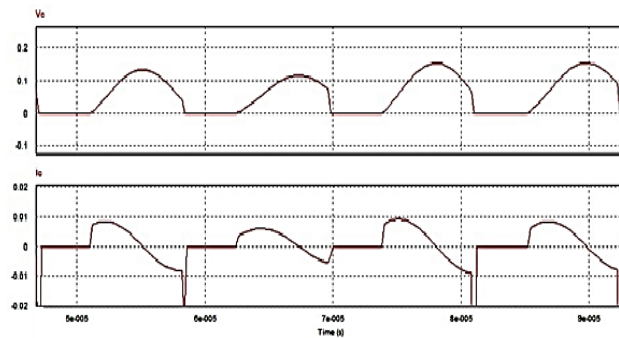


Fig. 12: Voltage and current waveforms of the resonant capacitor.

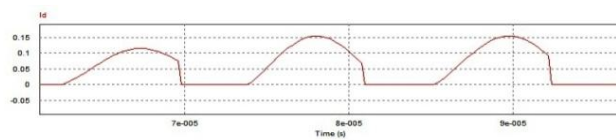


Fig. 13: Current waveform through the diode D.

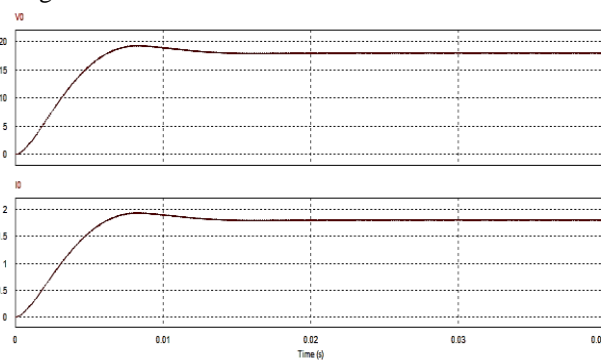


Fig. 14: Load voltage and current waveforms.

REFERENCES

Cuzner, R.M., D.J. Nowak, A. Bendre, G. Oriti and A.L. Julian, 2007. "Mitigating circulating common-mode currents between parallel soft-switched drive systems," *IEEE Trans. Ind. Appl.*, 43(5): 1284-1294.

da Silva Martins, M.L., J.L. Russi and H.L. Hey, 2006. "Novel design methodology and comparative analysis for ZVT PWM converters With resonant auxiliary circuit," *IEEE Trans. Ind. Appl.*, 42(3): 779-796.

Emrani, A., E. Adib and H. Farzanehfard, 2012. "Single-switch soft-Switched isolated DC-DC converter," *IEEE Trans. Power Electron.*, 27(4): 1952-1957.

Ilic, M. and D. Maksimovic, 2007. "Interleaved zero-current-transition buck Converter," *IEEE Trans. Ind. Appl.*, 43(6): 1619-1627.

Kwon, J.M., W.Y. Choi and B.H. Kwon, 2009. "Single-switch quasi-Resonant converter," *IEEE Trans. Ind. Electron.*, 56(4): 1158-1163.

Li, W., J. Xiao, Y.I. Zhao and X. He, 2012. "PWM plus phase angle shift (PPAS) control scheme for combined multiport DC/DC converters," *IEEE Trans. Power Electron.*, 27(3): 1479-1489.

Liu, F., J. Yan and X. Rua, 2010. "Zero-voltage and zero-current-switching PWM combined three-level DC/DC converter," *IEEE Trans. Ind. Electron.*, 57(5): 1644-1654.

Park, K.B., C.E. Kim, G.W. Moon and M.J. Youn, 2009. "PWM Resonant single-switch isolated converter," *IEEE Trans. Power Electron.*, 24(8): 1876-1886.

Rahimi, A.M. and A. Emadi, 2010. "Discontinuous-conduction mode DC/DC Converters feeding constant-power loads," *IEEE Trans. Ind. Electron.*, 57(4): 1318-1329.