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Soft-Switching Front-End Boost Converter Based Fullbridge Inverter For Residential Power System

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ABSTRACT: Building a DC-DC converter with high step-up, low cost and high efficiency from low DC voltage is the requirement in many applications. It is achieved by employing a front-end boost converter based full-bridge inverter. In conventional boost converter during device turn-off, voltage overshot occurs across the semiconductor devices. So, an additional snubber or voltage clamping is required to limit the overshot voltage. It increases the component's count and losses making the converter less efficient. The above problem is eliminated by operating the converter with soft-switching achieved by using secondary modulation technique. Hence, it avoids the need of additional snubber or auxiliary circuit. The presence of voltage doubler configuration reduces the number of switches leading to compact design. The control system is adaptive to wide variation input changes by employing fuzzy logic control scheme. The theoretical analysis of the proposed converter is verified using simulation and experimental results.

KEYWORDS: Boost converter, residential power system, resonant technique and soft-switching.

I. INTRODUCTION

The conventional power generation method faces problems like depletion of fossil fuels and polluting the environment. Also because of the increasing demand and energy crisis, world's power production has shifted hugely towards renewable energy systems. Additionally, the source is freely available and is pollution free. Solar PV is one of the fast growing methodologies among the renewable energy systems accounting for 1/3 of the world's power production by 2030. In solar PV the major factor to be overloaded is the low DC voltage produced from the solar panel and also the non-uniform nature of the source. The power production is also affected due to partial shading and panel mismatch. Hence the project lies to provide a DC-DC converter with high step-up, low cost and high efficiency. The boost converter is the preferred choice in earlier days because of its high voltage gain and simple circuit structure. But the power level is limited due to hard switching operation which also increases switching losses leading to less efficiency. To increase the power level, power device parallel technology is one of the solutions. However, this method cannot reduce the input and output current ripples. Interleaved structure is another effective solution to increase the power level which can minimize the current ripple, can reduce passive component size, can reduce the passive component size, can improve the transient response and can realize the thermal distribution. However, the power devices still operate at hard switching leading to less efficiency.

The aim of this project is to achieve soft switching (ZCS of primary side and ZVS of secondary side) of all semiconductor devices. The objective of this project is to provide an efficient DC-DC conversion in Residential solar power system. A novel secondary modulation technique is proposed to clamp the voltage across the primary side devices and therefore eliminates the necessity for snubbers. Switching losses are reduced significantly owing to Zero-Current Switching (ZCS) of primary switches and Zero-Voltage Switching (ZVS) of Secondary switches. Soft switching is inherent, load independent, and is maintained with wide variation of input voltage and power, and thus is suitable for PV applications. The boost converter may be used in conjunction with a high frequency transformer to boost the output voltage with the advantage of providing isolation n between the input and output stage. Without

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extreme duty cycle and high switch voltage stress that exists in the conventional boost converter the proposed converter achieves high step-up, low cost, and high efficiency front end DC-DC conversion thus suited for PV application. The boost converter is usually the preferred choice in high power switching transformer applications exceeding one kilowatt.

II. LITERATURE SURVEY

Soft-switching current-fed half-bridge frontend isolated DC-DC converter base inverter for AC module applications was proposed. The converter attains clamping of the device voltage by secondary modulation, thus eliminating the need of snubber or active clamp. This paper is used as a reference for understanding the benefits of soft-switching and the method of attaining it. [1]

Safety enhanced high step-up DC-DC converter for AC photovoltaic module application was proposed. To protect installers and users from electrical hazards Chen proposed a converter that employs floating active switch to isolate energy from the PV panel when the AC module is off. This paper is used as a reference for achieving high step-up voltage conversion ratio, without extreme duty ratio and the numerous turns- ratios of a coupled inductor. [2]

The development of a high efficiency bidirectional converter for power sources with great voltage diversity was focused. This paper is used as a reference for mitigating the switching losses by employing transformer based circuit topologies and frequently applying soft switching techniques including zero voltage switching (ZVS) or zero current switching (ZCS). The techniques of voltage clamping, synchronous rectification and soft switching are exploited thus providing high efficiency bidirectional power conversion for power sources with large voltage diversity. [3]

ZVT PWM three level boost converters for power factor pre-regulator were proposed. The benefit is using one auxiliary switch in active soft switching circuit. This paper is used as a reference for achieving zero voltage turn-on and zero voltage turn-offs of the main switches and reducing the reverse recovery loss of boost diode. In addition the auxiliary switch achieves ZCS during turn-on switching transition thus featuring the effectiveness of the converter. [4]

Generalized structure of bi-directional switched capacitor DC-DC converters that feature voltage step-up and bi-directional power flow was presented. This paper is used as a reference for current control which is applied in the capacitor-charging phase, resulting in a near constant capacitor charging current and low electromagnetic interference. Two similar strings are parallel connected and operated in anti-phase so that the overall converter input current becomes continuous and high efficiency is achieved. [5]

Overview of inverters for single phase grid connected photovoltaic system was proposed. This paper is used as a reference for understanding the development of relevant international industry standards affecting PV inverter technology. The author gives details not only on the topologies commercially available but also on the switching devices employed and the associated switching frequencies, efficiency, price trends and market share. [6]

The design of a non-dissipative turn-off snubber in a forward converter was presented. This paper is used as a reference for reducing the auxiliary devices thereby achieving high efficiency with low components count. The optimum size of the snubber capacitor is derived from the evaluation of transistor energy loss and surge voltage. The condition that minimizes the energy loss is determined thus obtaining the optimum size of the snubber inductor. [7]

III.PROPOSED METHOD

Soft switching can be used to solve some of the mechanisms of switching loss and thereby used to reduce the generation of EMI. Semiconductor devices are switched on or off at the zero crossing of their voltage or current waveforms. The ZCS turn-on of a converter can be made by connecting an inductor in series as the current flowing through an inductor cannot change immediately. Connecting an inductor in series with a switch makes the current flowing through the other devices in the converter to gradually decrease so that they can turn-off with ZCS. The ZCS turn-off of the switch is done by providing another path for the current to flow through, before the switch is turned off. Since the switch has small voltage drop, the other path must be at a lower voltage potential so that current can be diverted from the switch. The recent development relates to ZCS resonant converters such as Buck ZCS resonant converters for mitigating the high frequency switching losses and reducing circuit size. The switches of ZCS resonant converters turn ON and OFF at zero current due to the current produced by LC resonance flows through the switch.

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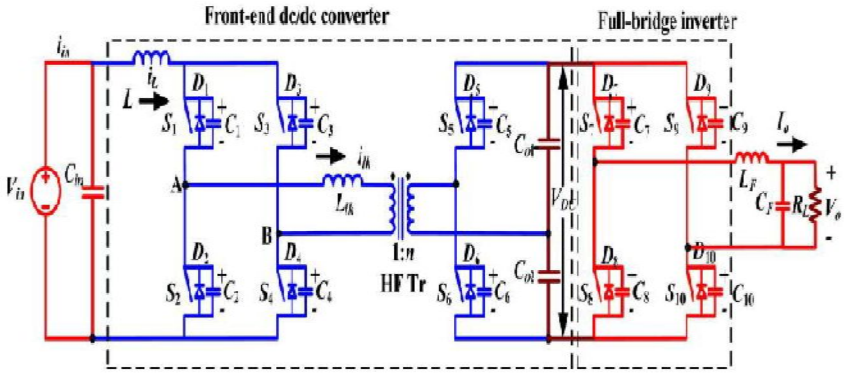

Figure 1: Circuit diagram of the proposed system

a. ZERO CURRENT SWITCHING

In ZCS technique as shown in Figure 2a, the switching occurs at zero current. Zero-current switching eliminates the switching loss caused by IGBT and by stray inductances. It can also be used to commutate thyristors. The ZCS is a type of soft switching technique. Reducing stress on the switching components is a significant aspect for resonant operation; and the ways it can be achieved has to be understood. The simplest way is to reduce the current flowing through the switch being induced to rise gradually after the switch is turned-on so that it has a ZCS turn-on. The switch current is also being induced to decrease gradually before the switch is turned-off so that it can have a ZCS turn-off. The ZCS of primary side switches and ZVS of secondary side switches is achieved. Thus soft-switching of all semiconductor devices leads to reduction in switching losses.

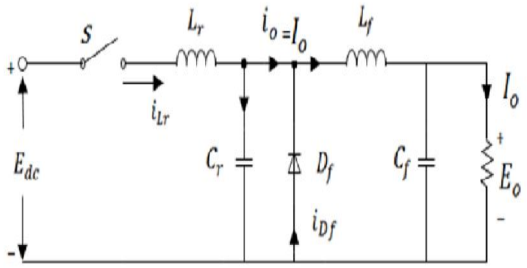

Figure 2(a)

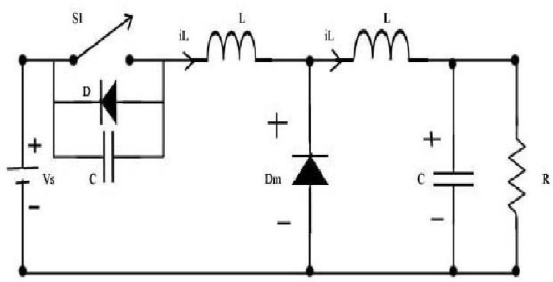

Figure 2(b)

Figure 2a: Zero Current Switching technique, Figure 2b: Zero Voltage Switching technique

The resonant circuit consists of a switch S, inductor Lr, and capacitor Cr. The LC circuit is used to store and transfer energy from input to output quite similar to the resonant converter. To achieve ZCS, the inductor Lr is connected in series with power switch S so that it has ZCS turn–on. Cr is connected across the main power diode. When the switch current is zero the current flowing through the internal capacitance due to finite slope of switch voltage at turn off. The current flow causes power dissipation and increases the switching frequency. In ZCS techniques, the turn off losing of switching devices are almost eliminated. Therefore the converter can be operated at higher frequencies, in the range of 1MHz to 2MHz. The advantages of Buck ZCS resonant converter that they have low switching losses due to resonance techniques, easy drive on switches and low stress on switching elements (MOSFET) as well. ZCS is formed by replacing the power switches in PWM converters with ZC resonant switch. The output filter inductor is significantly large so that its current is constant. Prior to turning the switch on, the output current Io freewheels through the diode Df. The soft-switching is nothing but achieving ZCS of primary side switches and ZVS of secondary side devices. The soft-switching of all devices leads to reduction in switching losses and thereby increasing the efficiency. It also eliminates the problem of voltage overshoot thus reducing the components count.

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b. ZERO VOLTAGE SWITCHING

Zero voltage switching (as shown in figure 2b) is defined as conventional square wave power conversion during the switch's on-time with "resonant" switching transitions. It can be considered as square wave power utilizing a constant off-time control which varies the conversion frequency to maintain regulation of the output voltage. ZVS of secondary side devices is achieved. Zero Voltage Switching of secondary devices and Zero Current Switching of primary side switches are achieved resulting in soft-switching. The switch can be reactivated, and lossless zero voltage switching is achieved. Since the output capacitance of the MOSFET switch has been discharged by the resonant tank, it does not add to power loss or dissipation in the switch. Therefore, the MOSFET switching losses go to zero regardless of operating frequency and input voltage. This contributes to a significant savings in power, and result in a significant improvement in efficiency. This feature makes zero voltage switching a possible solution for high frequency, high voltage converter designs. Additionally, the gate drive requirements are significantly reduced in a ZVS design due to the lack of the gate to drain charge, which is eliminated when voltage equals zero. The technique of zero voltage switching is applicable to all switching topologies; the buck regulator and its derivatives (forward, half and full bridge), the fly back, and boost converters. Zero-Voltage Switching, the transistor turn on occurs at zero voltage. Diodes may also operate with zero-voltage switching. Zero-voltage switching eliminates the switching loss caused by diode stored charge the output capacitances of devices and switches.

IV. CIRCUIT SIMULATION

The simulation models are designed and explained in matlab/simulink. The resonance techniques are being implemented in boost converter to reduce switching losses by achieving soft switching leading to higher efficiency. ZCS and ZVS are achieved using secondary modulation technique which is inherent and is independent of the load. Current through input boost inductor, voltage across primary switches, current through primary and secondary switches and voltage across output capacitors are measured along with output voltage for analysing the operation of front-end boost converter. The MATLAB model for boost resonant converter is designed in MATLAB/Simulink environment and simulation results are verified. MOSFET is used for the first inverting stage due to its high frequency operation. MOSFET is also used for rectification stage. For the final inversion stage IGBTs are used due to its high power ratings. Soft-switching is achieved by means of secondary modulation technique. The usage of transistors, known for their controlled operation (turn-on and turn-off by means of control circuit) makes commutation easier and thereby soft switching is achieved.

V. SIMULATION RESULTS

Simulated results of the project are shown and discussed. It also ensures the proper working of the model. From a 12V DC supply, 230V AC supply is obtained suitable for residential power system. The output waveforms of various devices are shown. The current through boost inductor, Voltage across primary switches, Voltage across output capacitors, Primary and secondary switch currents, Output voltages along with Zero Current Switching of primary side switches and Zero Voltage Switching of secondary devices are taken and simulation results are verified.

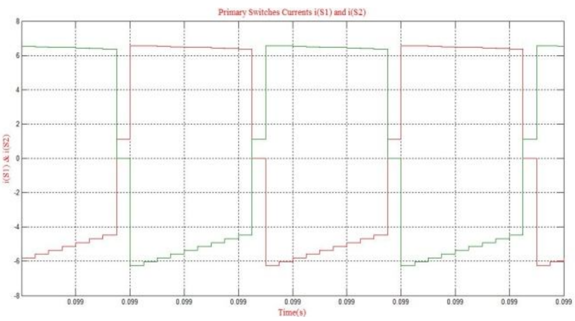

Figure 3(a)

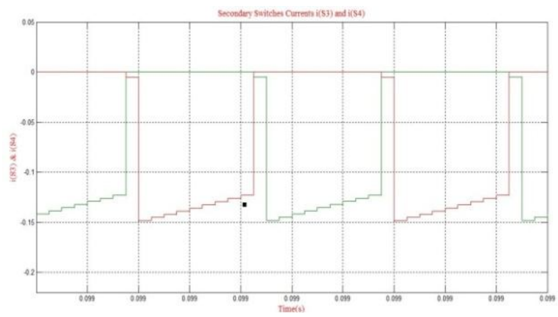

Figure 3(b)

Figure 3a: Primary switches currents i_{s1} & i_{s2}, Figure 3b: Secondary switches currents i_{s3} & i_{s4}

The use of boost converter results in high voltage gain. The use of resonant technique reduces switching losses resulting in high efficiency. It is verified by simulation results.

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Figure 3a shows the waveform of current through primary switches. The waveform clearly shows that the two primary switches alternate each other. The boost converter is a three stage DC-DC conversion. First the 12V DC voltage is converted in to AC voltage and stepped up using transformer and rectified to 300V DC voltage using rectifier. The full-bridge inverter is used to convert the DC voltage to 230 V AC voltages suitable for residential power system. Voltages across output capacitors are shown.

Figure 3b shows the waveform of current through secondary switches. The waveform clearly shows that the two secondary switches alternate each other.

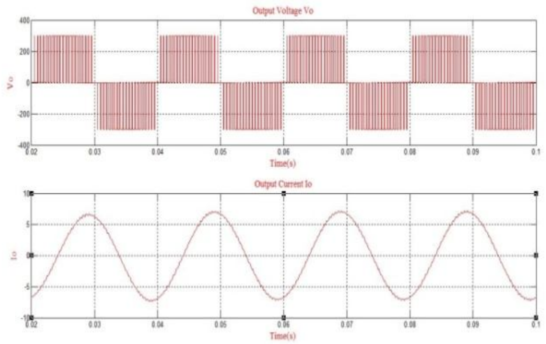

Figure 4(a)

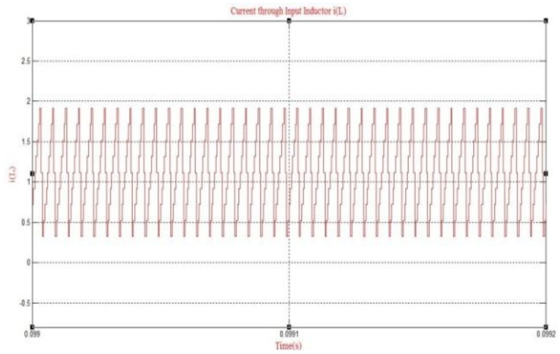

Figure 4(b)

Figure 4a: Output voltage v_o & output current i_o, Figure 4b: Current through input inductor I_L

Figure 4a shows the waveform of output AC voltage and current. The magnitude of the rms output voltage is 230 volts. Thus a 22 volt DC supply is stepped up to 300 volt DC using front-end boost converter. This is further converted to 230 volt AC by using full bridge inverter. The transformer is also used for isolation purpose, thus giving protection from non-uniform nature of the load.

Figure 4b shows the waveform of current through boost inductor. Its magnitude lies in the range of 0 and 2 Amps. The inductor is used for stepping up the input DC voltage, hence also called as boost inductor.

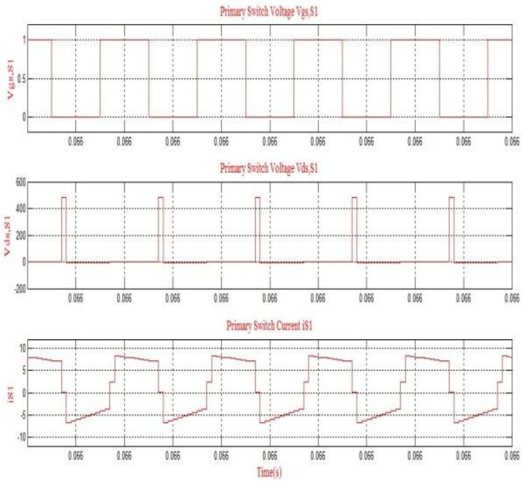

Figure 5(a)

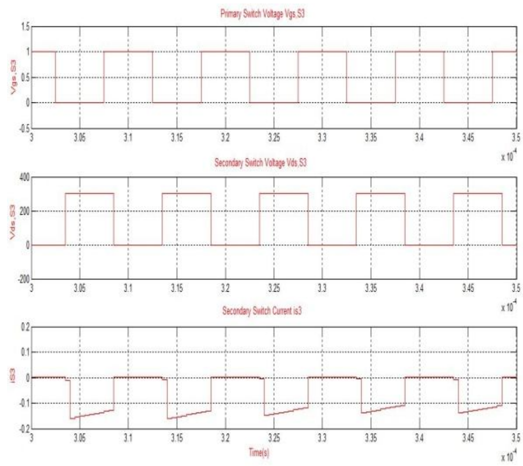

Figure 5(b)

Figure 5a: Primary switch voltages ($v_{gs,s1}$&$v_{ds,s1}$)&current $i_{s1,}$ Figure 5b: Secondary switch voltages ($v_{gs,s3}$&$v_{ds,s3}$)& current i_{s3}

Figure 5a shows the primary switch voltages (gate source and drain source voltages) and current. The primary switch S1 achieves Zero Current Switching (ZCS) leading to soft-switching. Thus ZCS of primary side is achieved using resonant technique.

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Figure 5b shows the secondary switch voltages (gate source and drain source voltages) and current. The primary switch S3 achieves Zero Voltage Switching (ZVS) leading to soft-switching. The ZCS of primary side switches and ZVS of secondary side devices lead to reduction in switching losses and thereby resulting in improved efficiency. Thus by using secondary modulation technique, soft switching of all semiconductor devices is achieved.

VI. CONCLUSION

A resonant power conversion scheme using DC-DC converter with AC link has been proposed and validated through MATLAB/Simulink simulations. The proposed system is a two-stage single-phase inverter consisting of high step-up front end boost converter followed by full-bridge inverter for the residential power system. The conventional current-fed boost converter gets affected by voltage overshot which occurs across the semiconductor devices at turn-off. Therefore, voltage clamping or snubber circuits are required to limit the device voltage. It increases components' count, cost, and losses. The proposed innovative secondary modulation achieves the soft-switching of all semiconductor devices (ZCS of primary side and ZVS of secondary devices) without modifying the topology. It solves the basic problem of device turnoff in current-fed converter. The device voltage is clamped naturally by secondary modulation without active clamping or passive snubbers. Switching losses are reduced significantly owing to ZCS of primary switches and ZVS of secondary switches. In addition, soft switching is inherent, independent of the load and is maintained with variation in source voltage. Soft switching permits high switching frequency operation leading to design compact, low cost, light weight system and high efficiency over wide range of load and input voltage.

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