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A Simple Phase Shift Controlled DC-DC Converter for High Voltage Applications

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ABSTRACT— *With rapid development of renewable energy there is a rise in utilization of isolated DC-DC converters for applications like smart grid and electric vehicles. High efficiency, high gain and high power density are the parameters expected from a normal DC-DC converter, but when it comes to the output voltage, it will be of poor quality. The use of a transformer in the above system can correct this fault. This transformer isolates the Active Boost Rectifier (ABRs) which is composed of a traditional diode rectifier and a switch along with a Voltage Doubler(VD). Replacing inverter with an interleaved DC-AC converter on the primary side helps to generate a voltage from equal or lower input supply. This system can be useful anywhere where one does not have access to mains outlet for example a car, trailer or cottage. It can power appliances like radios, tape recorders, televisions, electric shavers, fluorescent lamps or cell phone charger. A voltage multiplier if implemented instead of the ABR-VD produces high voltage gain and can be used for high voltage applications , this is realized using fast switching diodes with addition of a phase shift control which provides gate pulses for switches on the inverter side by shifting phase angle and producing delay in pulses. This technique if utilized gives better performance parameters for DC-DC converter such as voltage gain, low voltage stress and soft switching behaviour. Various control strategies to suit high voltage low current application is considered giving more importance to phase shift control scheme and implementing it with a suitable closed loop controller for complete control is done.*

Keywords— Interleaved Converter, Voltage Doubler, Soft Switching, Distributed Voltage.

1, INTRODUCTION

DC-DC converters are important in most of the portable electronic devices and are employed in variety of applications including supply for personal computers, office equipment, spacecraft power systems, laptops, telecommunication equipments as well as DC motor drives. The input to a basic DC-DC converter is an unregulated DC voltage say V_{in} and the converter produces a regulated output voltage say V_{out} which is having a magnitude and sometimes polarity that differs from that of the input voltage. High efficiency is invariably required for a converter since cooling of power converters is difficult and expensive. The ideal DC-DC converter exhibits 100% efficiency but in practice efficiencies of 70% to 95% are typically obtained, this is achieved using switched mode or chopper circuits whose elements dissipate negligible power. Various techniques allows control and regulation of the total output voltage. This controlling approach is employed in applications involving alternating current, including high efficiency DC-AC power converters (inverters and power amplifiers), AC-AC power converters and some AC-DC power converters (low harmonic rectifiers).In the majority of applications it is desired to incorporate a transformer into the switching converter, to obtain dc isolation between the converter input and output. For example in off-line power supply applications, isolation is usually required by regulatory agencies. This isolation could be obtained by simply connecting a 50 Hz or 60 Hz transformer at the power supply AC input terminals. However, since transformer size and weight vary inversely with frequency, incorporation of the transformer into the converter can make significant improvement.

When a large step-up or step-down conversion ratio is required, the use of a transformer can allow better converter optimization. By proper choice of the transformer turns ratio the voltage or current stresses imposed on the transistors and diodes can be minimized, leading to improved efficiency and lower cost. The ratio of turns on primary side to secondary side of a transformer is same as the ratio of voltage at primary to that of secondary but inverse of current value of primary to secondary.

2, FULL BRIDGE DC-DC CONVERTER

DC-DC converters are used to convert DC voltage from one voltage level to another. They can be step up or step down. Mostly power electronic converters consist of semiconductor switches like MOSFETs and IGBTs. DC-DC converters are classified into non isolated and isolated converters. A transformer is present in the isolated topology which provides isolation between the input and the output. The non-isolated converters are buck (step down) converter, boost converter (step up) converter, buck boost converter and cuk converter. The various isolated converters are forward converter, flyback converter, push pull converter, half bridge converter and full bridge converters. In recent years the high power isolated DC-DC converters has developed in the market due to its requirement in the applications like fuel cell applications, battery based storage systems and telecommunications systems etc. In most of the applications the transformer is incorporated due to the circuit to provide isolation. The advantages of using isolation is that the transformer present in the isolated topology can provide large step up or step down conversion ratio, multiple dc outputs can be obtained by providing multiple secondary windings, voltage and current stress in the transistors can be reduced by proper design of turns ratio. The basic requirement of a converter is small size and high efficiency. To achieve small size high switching frequency operation is necessary but the switching losses increases with increase in switching frequency. The solution for this problem is using soft switching techniques such as Zero Voltage Switching (ZVS) and Zero Current Switching (ZCS) these techniques provide zero voltage or current during switching transitions and thus reduce switching losses.

Full bridge converters are mostly used in medium to high power applications. The output voltage can be controlled by two methods Pulse Width Modulation(PWM) control and phase shift control. The full bridge configuration used for high input voltage and high power applications is the phase shifted full bridge DC-DC converter. Phase Shifted Full Bridge DC-DC converter (PSFB) is similar to the conventional full bridge DC-DC

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converter but with a phase shifting control. In phase shifted full bridge DC-DC converter, the switches attain zero voltage switching which reduces the switching losses and the converter can attain high efficiency at high switching frequencies. It has benefits such as low switching noise and it doesn't require additional snubber circuits to reduce losses. PSFB converters are used to step up or step down dc voltages and to provide isolation in medium to high power applications such as renewable energy systems, telecom rectifiers, battery charging systems, server power supplies

3, CONVERTERS AT SIDES OF FBC

The input voltage depends on the design and purpose of the inverter. An inverter converts the DC from sources such as batteries or fuel cells to AC form. An inverter can produce a square wave, modified sine wave, pulsed sine wave, Pulse Width Modulated (PWM) wave or sine wave depending on circuit design. The two dominant commercialized waveform types of inverters as of now is modified sine wave and sine wave. There are two basic designs for producing household plug-in voltage from a lower voltage DC source, the first of which uses a switching boost converter to produce a higher voltage DC and then converts to AC. The second method converts DC to AC at battery level and uses a line-frequency transformer to create the output voltage. The AC output frequency of a power inverter device is usually the same as standard power line frequency, 50 hertz. The AC output voltage of a power inverter is often regulated to be the same as the grid line voltage, typically 230 V even when there are changes in the load that the inverter is driving. This allows the inverter to power numerous devices designed for standard line power. Some inverters also allow selectable or continuously variable output voltages. A power inverter will often have an overall power rating expressed in watts or kilowatts. This describes the power that will be available to the device the inverter is driving and indirectly the power that will be needed from the DC source.

A full wave rectifier converts the whole of the input waveform to one of constant polarity (positive or negative) at its output. Full wave rectification converts both polarities of the input waveform to pulsating DC, and yields a higher average output voltage. Similar to the half wave circuit a full wave circuit as used in the FBC-ABR VD produces an output voltage or current which is purely DC or has some specified DC component. Full wave rectifiers have some fundamental advantages over their half wave rectifier counterparts. The average DC output voltage is higher than that of half wave, the output of the full wave rectifier has much less ripple than of the half wave rectifier producing a smoother output waveform. In a full wave rectifier circuit two diodes are used, one for each half of the cycle. A multiple winding transformer is used whose secondary winding is split equally into two halves with a common centre tapped connection. This configuration results in each diode conducting in turn when its anode terminal is positive with respect to the transformer centre point producing an output during both half cycles and produces an output which is twice that of a half wave rectifier. Cascaded diode and capacitor stages can is added to make a voltage multiplier (Cockroft-Walton Circuit). These circuits are capable of producing a DC output voltage potential tens of times that of the peak ac input voltage, but are limited in current capacity and regulation. Diode voltage multipliers frequently used as a trailing boost stage or primary High Voltage (HV) source are used in HV laser power supplies, powering devices such as Cathode Ray Tubes (CRT) (like those used in CRT based television, radar and sonar displays), photon amplifying devices found in image intensifying and Photo Multiplier Tubes (PMT) and magnetron based Radio Frequency (RF) devices used in radar transmitters and microwave ovens. Before the introduction of semiconductor electronics transformer less powered vacuum tube receivers powered directly from AC power sometimes used voltage doublers to generate DC high voltages.

4, FBC AND AN INTERLEAVED TWO SWITCH CONVERTER AT PRIMARY

For a FBC-VD-ABR all the switches on the primary and secondary sides have a constant duty cycle of 0.5. Q_1 and Q_4 are always turned ON/OFF simultaneously and the same with Q_2 and Q_3. A phase shift angle between the primary and secondary side active switches is employed to regulate the output power and voltage. L_f stands for the total of the transformer leakage inductance and external inductor. The output series capacitors C_{o1} and C_{o2} have the same capacitance and are large enough to clamp the voltage stresses of the secondary side switches and diodes to half of the output voltage. u_{DS1}, u_{DS4}, and u_{DS6} are the drain to source voltages of Q_1, Q_4, and Q_6, respectively. u_P and u_S are the voltages on the primary side and secondary side of the transformer. And i_{Lf} is the primary current flowing through the transformer. A proper dead time is necessary for the primary side switches to achieve ZVS. To simplify the analysis, the parasitic capacitance of MOSFET is ignored and the transformer is assumed to be ideal the state of operation of interleaved converter on primary is as follows

State a:

At time t0, Q1 is closed and Q2 is opened. The current of the inductor L1 starts to rise, while L2 continues to

discharge. The rate of change of iLl is diLl/dt = Vi/L, while the rate of change of iL2 is diL2/dt = (Vi –Vo)/L.

2). State b:

At time t1, Q1 and Q2 are opened. The inductors L1 and L2 discharge through the load. The rate of change of iLl

and iL2 are diLl/dt = diL2/dt = (Vi –Vo)/L.

3). State c:

At time t2, Q2 is closed while Q1 still opened. The current of the inductor L2 starts to rise, while L1 continues to

discharge. The rate of change of iL2 is diL2/dt = Vi/L, while the rate of change of iL1 is diL1/dt = (Vi –Vo)/L.

4). State d:

At time t3, Q2 is opened and Q1 still opened. The situation is same as state b. The inductors L1 and L2 discharge

through the load. The rate of change of iLl and iL2 are diLl/dt = diL2/dt = (Vi –Vo)/L.

Due to the symmetry of the circuit, the next state is similar to the previous as they are in symmetry

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5, CONTROLLING OF CONVERTERS

Phase Shifted Full Bridge (PSFB) DC-DC converters are used frequently to step down high DC bus voltages and provide isolation in medium to high power applications like server power supplies, telecom rectifiers, battery charging systems and renewable energy systems. Traditionally micro controllers have been restricted to only performing supervisory or communications tasks in these systems. With the availability of high performing micro-controller devices, it is now possible to use micro controllers for closing control loops in these systems, in addition to handling the traditional micro controller functions. The transition to digital power control means that functions that were previously implemented in hardware are now implemented in software. In addition to the flexibility this adds to the system, this simplifies the system considerably. These systems can implement advanced control strategies to optimally control the power stage under different conditions and also provide system level intelligence. A PSFB converter consists of four power electronic switches (like MOSFETs or IGBTs) that form a full bridge on the primary side of the isolation transformer and diode rectifiers or MOSFET switches for Synchronous Rectification (SR) on the secondary side. This topology allows all the switching devices to switch with Zero Voltage Switching (ZVS) resulting in lower switching losses and an efficient converter. Here ZVS for switches in the one leg of the full bridge and zero or low voltage or low voltage switching for switches in the other leg is achieved across the complete load range, by changing dead times for primary side switches based on load conditions. For such an isolated topology, signal rectification is required on the secondary side. For systems with low output voltage and/or high output current ratings, implementing synchronous rectification instead of diode rectification which achieves the best possible performance by avoiding diode rectification losses. In this work, voltage doubler active boost rectification is implemented on the secondary side with different switching schemes to achieve optimum performance under varying load conditions. A DC-DC converter system can be controlled in various modes like Voltage Mode Control (VMC), Average Current Mode Control (ACMC) or Peak Current Mode Control (PCMC). Implementing these different control modes for controlling the same power stage typically requires redesigning the control circuit along with some changes to the power stage sensing circuit. With a microcontroller based system, all these modes can be experimented with on the same design with minimal or no additional changes. A system is implemented here using VMC and PCMC control schemes. PCMC is a highly desired control scheme for power converters because of its inherent voltage feed forward, automatic cycle by cycle current limiting, flux balancing and other advantages. Implementing PCMC for a PSFB system requires complex PWM waveform generation with precise timing control for PCMC implementation with a microcontroller, the regulated output voltage is dependent on the amount of output voltage ripple. Peak efficiency greater than 95% and efficiency greater than 90% down to 10% load is achieved for almost all converters.

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6, RESULT AND DISCUSSION

Simulation results of FBC-ABR-VD are shown in figures given below.

6.1 Input Voltage Waveform of FBC-ABR-VD

Simulation result of input voltage for FBC-ABR-VD is given in the figure.1. 120V DC supply is given as input.

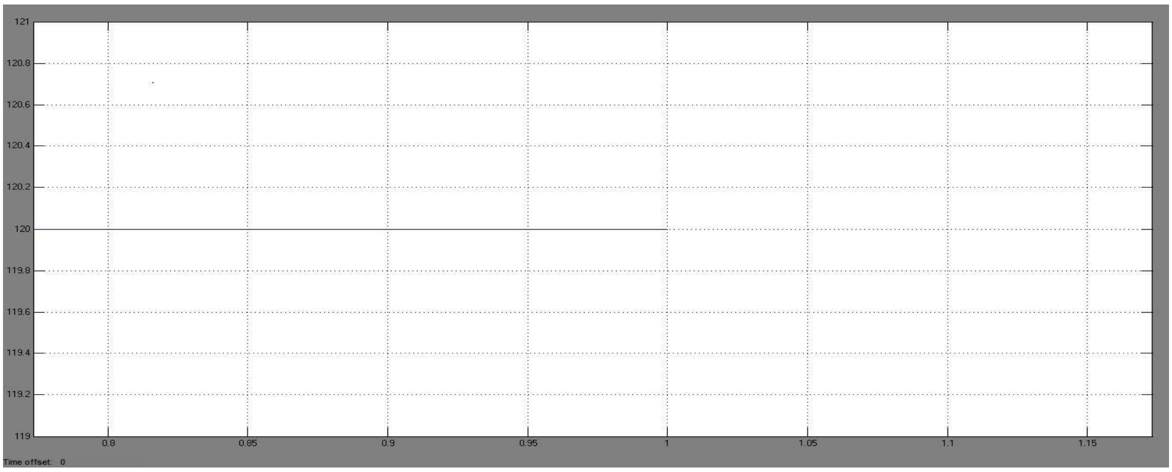

Figure.1 Input Voltage Waveform

6.2 Output Voltage Waveform of FBC-ABR-VD

Simulation result of output voltage for FBC-ABR-VD is given in the figure.2. 420V DC is obtained as output.

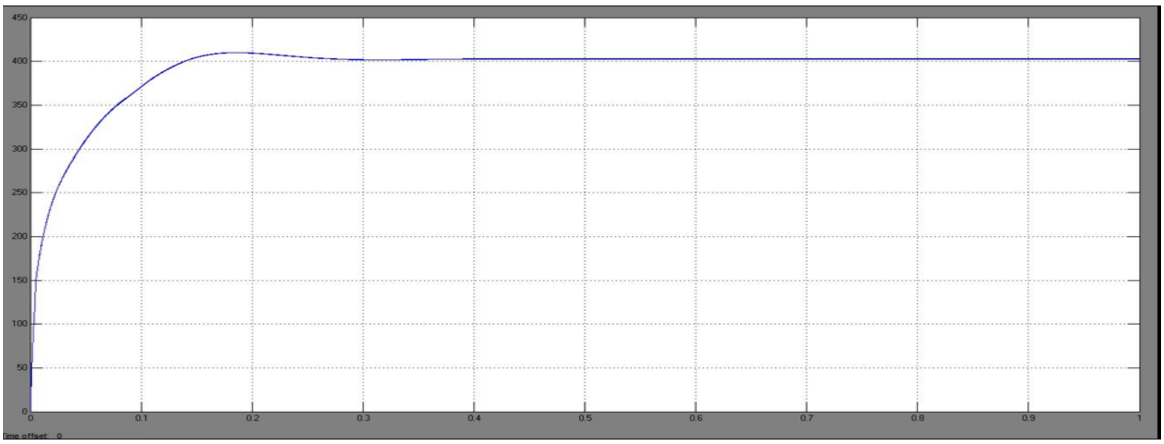

Figure.2 Output Voltage Waveform

6.3 Simulation Result of Interleaved-ABR-VD

Simulation results of Interleaved-ABR-VD with a multi winding transformer are shown in figures given below.

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6.3.1 Input Voltage Waveform of Interleaved-ABR-VD

Simulation result of input voltage for Interleaved -ABR-VD is given in the figure.3. 6V DC supply is given as input.

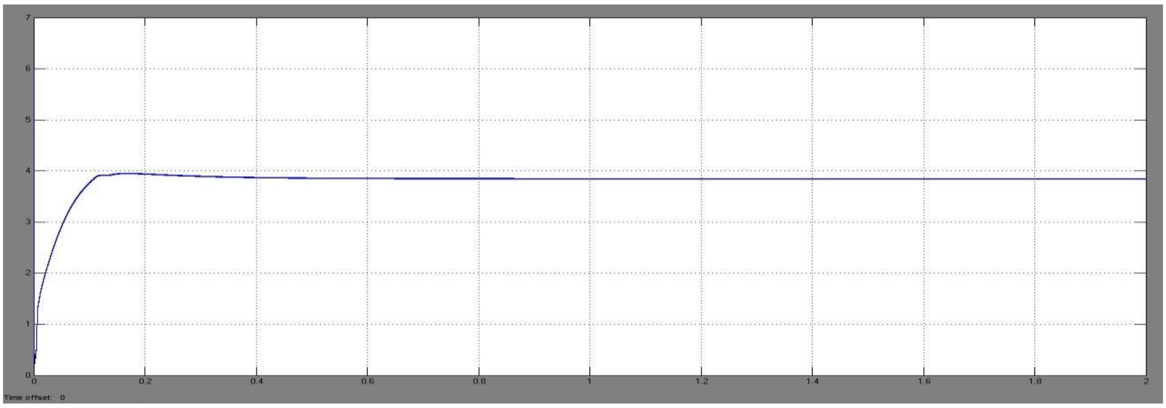

Figure.3 Input Voltage Waveform

Simulation result of phase shifted inputs for switches of Interleaved -ABR-VD is given in the figure.4.

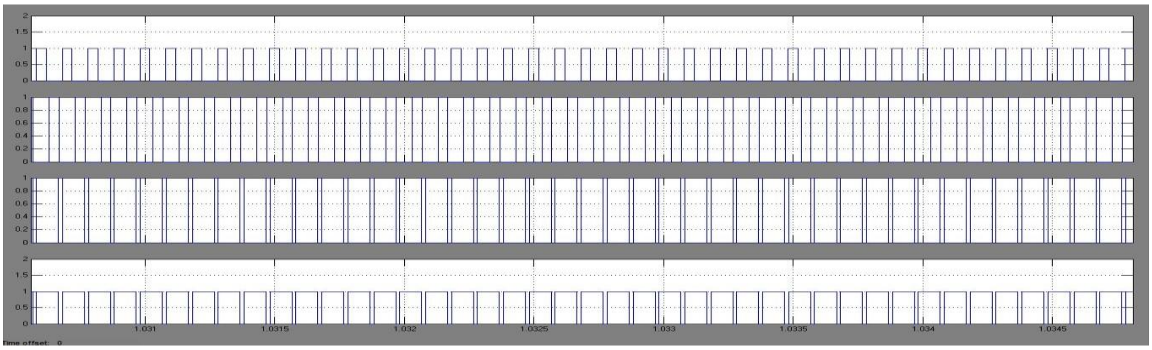

Figure.4 Control Signals for Switches

6.3.2 Output Voltage Waveform of Interleaved-ABR-VD

Simulation result of output voltage for Interleaved-ABR-VD is given in the figure.5. 82V DC is obtained as output.

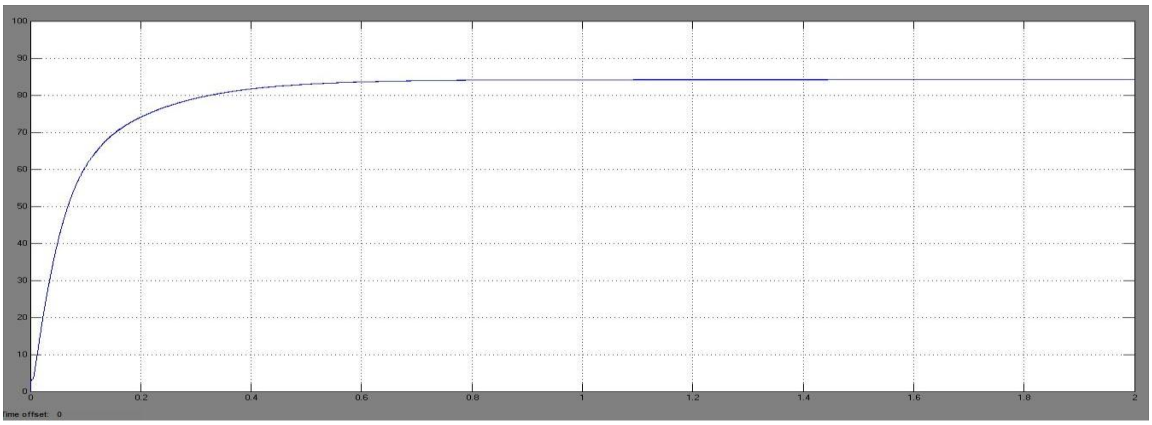

Figure.5 Output Voltage Waveform

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Simulation result of Interleaved-ABR-VD is given in the figure.6. and in figure.7 which explains the zero crossing points of switches for the system. The voltage as well as current spikes are obtained at zero crossing points.

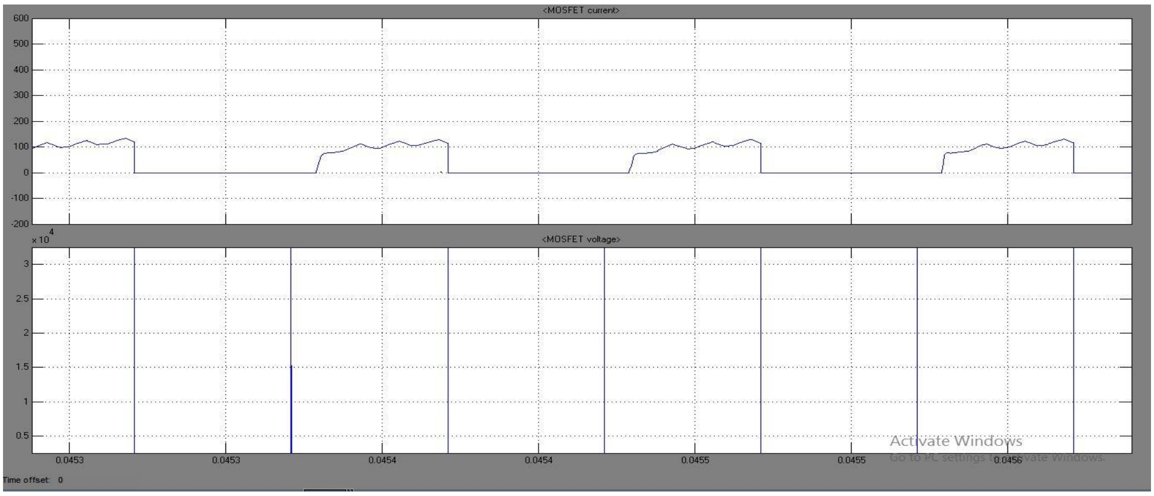

Figure.6 Zero Crossing at Switches

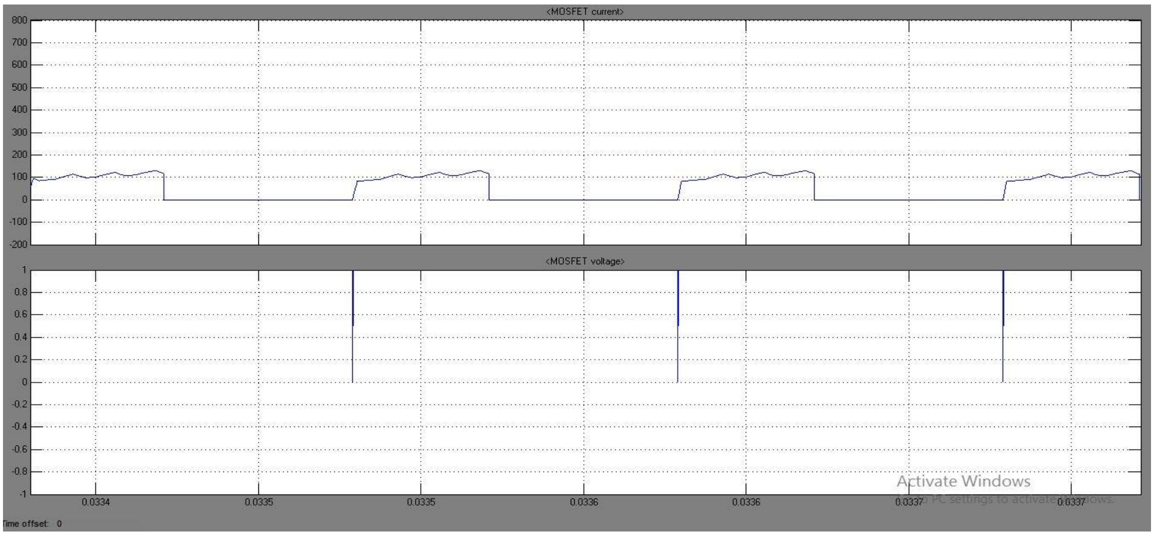

Figure.7 Zero Crossing at Switches of Secondary

VIII. CONCULSION AND FUTUREWORK

In the ABR-VD converters all the power switches are operated at fixed 50% duty cycle, and the output voltage regulation is achieved by adopting phase shift control between the primary and secondary side switches. ZVS performance has been achieved for both the primary and secondary side switches in a wide voltage and load range. Furthermore, the reverse recovery problems associated with the rectifier diodes. From the survey conducted to know the developments in the field of isolated DC-DC converter it is understood that if an interleaved converter on primary side is used for high voltage applications the topology will be having smaller voltage drop, faster dynamic response, lesser component count and lesser complexity and also the phase shifted DC-DC converter which can solve the problems of full bridge DC-DC converter such as high switching losses, conduction losses and lower efficiency. A possible modification of the SVM to a hybrid form is under consideration.

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