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Zero Voltage Switching Technology

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Abstract: *zero voltage switching defines that the power to the load is switched ON or OFF only when the output voltage is zero volt . As controller with zero voltage switching uses TRIAC instead of mechanical relay gives better control of controller so that life of controller extends and reduce the chances of arcing . ZVS technique used at high voltage and at high frequency without reducing efficiency as it reduces the conduction losses ,lowers the driving current and energy density is increases.*
Index Terms : *Zero Voltage Switching (ZVS) , Pulse Width Modulation (PWM) , Integrated Circuit (IC) , Metal Oxide – Semiconductor Field Effect Transistor (MOSFET) .*

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I. INTRODUCTION

Zero Voltage Switching means that the power to the load (heater or cooler or other device) is switched on or off only when the output voltage is zero volts. Zero Voltage Switching can extend the life of a controller and of the load being controlled. Photovoltaic Micro-inverter Topology With Phase-Shift Power Modulation Controllers with Zero Voltage Switching use triacs instead of mechanical relays, and, in fact, all of our temperature controllers which use a triac are inherently Zero Voltage Switching. With AC current the voltage is zero 50 to 60 times a second. For example, with 120VAC at 60 Hz the voltage swings from 0 volts to -120 volts to 0 volts to +120 volts and back to 0 volts 60 times a second. The controller only turns the power to the load on or off when the voltage is zero. (Since the cycle described above repeats itself, there are, at 60 Hz, 120 times every second that the AC voltage is at zero volts and power switching can occur. With DC power, as used with thermoelectric controllers, the DC voltage is first converted by the controller to DC PWM - "DC voltage, Pulse Width Modulated". The lowest voltage of these DC pulses is zero, and so this power source for a load can also be switched on or off when the voltage is zero. The frequency of these pulses is high enough that a peltier device considers the DC PWM power to be simple DC power, and so pulsing the voltage in this way does not harm a peltier device. Zero Voltage Switching has an advantage over the kind of switching that would normally be accomplished with a relay because there is a reduced chance forarcing. A relay could turn the power on when the voltage is, say, 120VAC, and an electrical arc (spark) could result. Buck voltage regulation, an essential part of distributing power from a DC supply to its points of load (POLs), has typically been implemented with a PWM circuit. The PWM duty cycle is varied to accommodate the required voltage reduction. However a couple of factors have applied increasing pressure to regulator design. Firstly, power density is being forced up as continuously more powerful devices are designed onto boards without corresponding increase in footprint. Secondly, DC power supply voltage levels are tending to rise to minimize distribution losses, while device voltages are reducing to increase internal speed and efficiency. These trends combine to increase the voltage drop and associated switching losses across the regulator. For example, a process control system may call for regulation from 24 V to 3.3 V – a gap that would typically be covered using two regulation stages; increasing board space, cost and reliability issues. The regulator's switching frequency is also limited, as increased switching activity incurs more losses. This in turn limits the use of smaller passive components for filtering, penalising the density of the total solution. Although high-density PWM regulators have evolved with improved IC integration, MOSFETs and packaging, their design is no longer sufficient to meet the power demands they face. This is mainly due to switching losses within the regulator MOSFETs. These must be overcome or avoided to achieve any significant boost to regulator performance.

A better solution uses Zero Voltage Switching (ZVS) topology, which allows for operation at a higher frequency and at higher input voltages without sacrificing efficiency. While still PWM based, a separate phase is added to the PWM timing to allow for ZVS operation. Fig. 1 compares a conventional buck regulator with a version modified for ZVS operation. Utilizing the added phase, the ZVS type uses the clamp switch and circuit resonance to operate the high side (Q1) and synchronous (Q2) MOSFETs efficiently with soft switching, avoiding the losses they incur during conventional PWM operation and timing. Photovoltaic Micro-inverter Topology With Phase-Shift Power Modulation For example in the conventional circuit, as Q1 is turned on and Q2 turned off, a very high current flows through the MOSFET pair, since Q2's body diode appears as a short circuit during its reverse recovery time. Other losses arise due to discharging Q1's output capacitance, and to reverse recovery in Q2. These losses increase as the switching frequency or input voltage increases. By contrast the ZVS design addresses the high turn-on losses of the conventional regulator by eliminating high current body diode conduction prior to turn on of the high side MOSFET, bringing the D-S voltage of the high side MOSFET to zero or nearly zero and producing no high current spikes or damaging ringing. The ZVS action applied to Q1 removes its Miller effect at turn on, allowing the use of a smaller driver and lower gate drive. Step-down ("buck") DC-DC voltage regulator circuit design is getting harder because power density (W/m3) is rising, DC power supply voltage levels are rising, and silicon voltage demands are dropping in order to increase efficiency. The difference between the supply voltage and that required by the silicon creates a big drop across the regulator, increasing switching losses and ultimately limiting the device's switching frequency. For example, a process-control system may call for regulation from 24 to 3.3 V – a gap that would typically have to be covered using two regulation stages, thereby increasing board space, cost, and reliability issues. Moreover, limited switching frequency is a drawback because it forces engineers to use larger magnetic and other passive components for filtering circuits, increasing the solution size and working against power density. One solution enabling a return to faster switching frequency at higher input voltage and voltage drop is Zero Voltage Switching (ZVS). This technique, like virtually Photovoltaic Micro-inverter Topology With Phase-Shift Power Modulation all contemporary switching voltage regulators, uses pulse width modulation (PWM)-based operation, but with an additional separate phase to the PWM timing to allow for ZVS operation. ZVS enables the voltage regulator to engage "soft switching", avoiding the switching losses that are typically incurred during conventional PWM operation and timing.

ZVS and its advantages.

- **Hard-switching losses**

Most contemporary non-isolated buck voltage regulators incur high-switching losses due to the simultaneous occurrence of high-current and -voltage stress imposed on the regulator's integrated metal oxide semiconductor field-effect transistor (MOSFET) switch during the turn-on and turn-off transitions. These losses increase with switching frequency and input voltage and limit maximum frequency operation, efficiency, and power density. Hard switching occurs during the overlap between voltage and current when switching the MOSFET on and off. Voltage regulator manufacturers try to minimize the overlap to in turn minimize the switching losses by increasing the rate of change of current (di/dt) and voltage (dv/dt) in the switching waveform. Figures 1and 2 illustrate where the switching losses occur and show an actual switching waveform with fast-changing voltage designed to minimize these loss

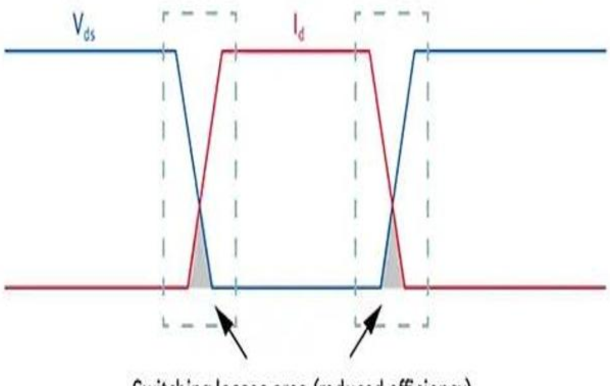

Figure 1: Voltage regulator losses occur during voltage/current overlap when the MOSFET switches (Courtesy of Infineon Technologies).

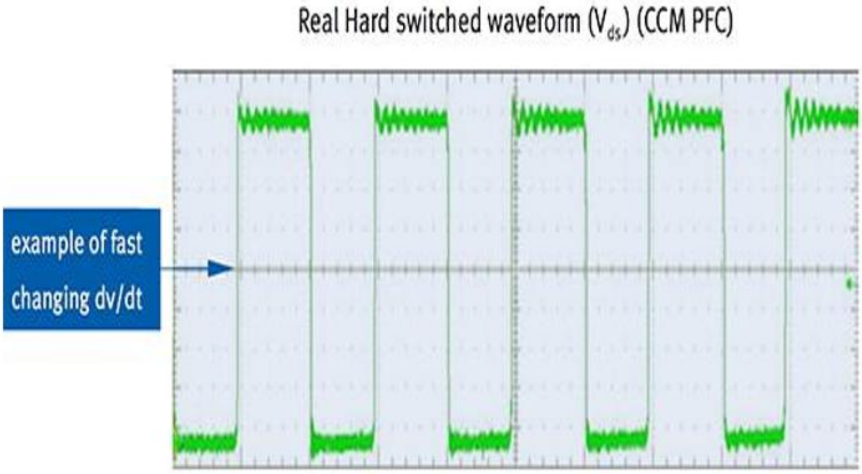

Figure2: Manufacturers increase dv/dt to minimize overlap and improve efficiency (Courtesy of Infineon Technologies).

The downside of fast switching is an increase in electromagnetic interference (EMI) emanating from the voltage regulator circuitry. One way to minimize EMI effects, while still taking advantage of fast switching to enhance efficiency, is to select a switching regulator that employs an improved hard-switching technique called quasi-resonant switching (also known as "valley" switching). Infineon Technologies offers a range of power MOSFETs, such as its Cool MOS series, for quasi-resonant flyback switching voltage regulators. During quasi-resonant switching the MOSFET is turned on when the voltage across drain and source is at a minimum (in a valley) in order to minimize the switching losses. This allows the device to operate with a more modest rate of change in voltage or current, and thus reduces EMI. Another positive side effect of quasi-resonant switching is that because switching is triggered when a valley is detected, rather than at a fixed frequency, a degree of frequency jitter is introduced, spreading the RF emission spectrum and further reducing EMI. Quasi-resonant switching does have the disadvantage of inducing higher losses at light loads, but the problem is eliminated in modern devices by employing a frequency-clamp circuit to limit the maximum operating frequency. Figure 2 shows a quasi-resonant switching waveform for a flyback converter where the MOSFET is switched in the valleys.

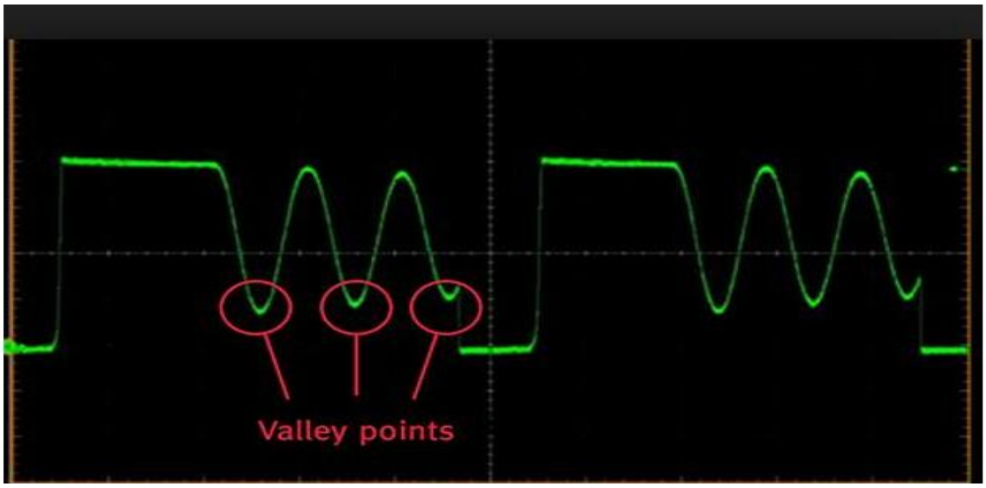

Figure 3 : Quasi-resonant switching waveform for a flyback converter (Courtesy of Infineon Technologies). Soft switching at zero voltage

Quasi-resonant switching is a good technique for improving voltage-converter efficiency, but things can be further improved by implementing full soft switching. During soft switching the voltage falls to zero (rather than just a minimum) before the MOSFET is turned on or off, eliminating any overlap between voltage and current and minimizing losses. (The technique can also be used to switch the MOSFET when current, rather than voltage, reaches zero. This is known as Zero Current Switching (ZCS).) An additional advantage is that the smooth switching waveforms minimize EMI (Figure 4).

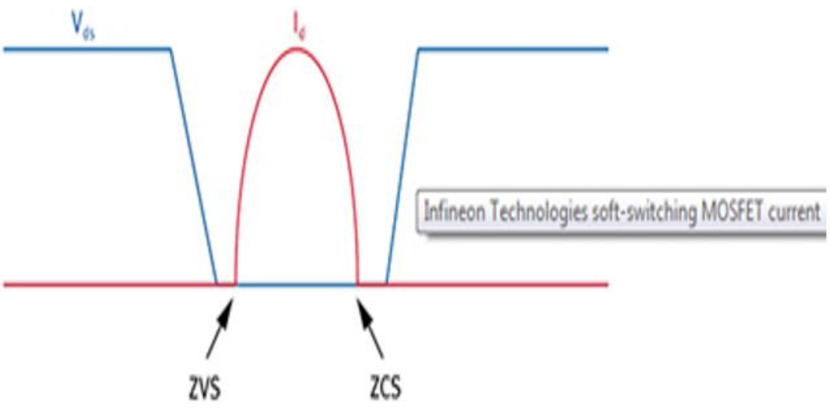

Figure 4: Soft-switching MOSFET current and voltage waveform (Courtesy of Infineon Technologies).

Soft switching (ZVS) can best be defined as conventional PWM power conversion during the MOSFET's on-time but with "resonant" switching transitions. The technique can be considered PWM power utilizing a constant off-time control which varies the conversion frequency, or on-time to maintain regulation of the output voltage. For a given unit of time, this method is similar to fixed-frequency conversion using an adjustable duty cycle. Regulation of the output voltage is achieved by adjusting the effective duty cycle (and thus on-time), by varying the conversion frequency. During the ZVS switch off-time, the regulator's L-C circuit resonates traversing the voltage across the switch from zero to its peak and back down again to zero when the switch can be reactivated, and lossless ZVS facilitated. The MOSFET transition losses are zero— regardless of operating frequency and input voltage—representing a significant savings in power, and a substantial improvement in efficiency (Figure 4). Such attributes make ZVS a good technique for high-frequency, high-voltage converter designs.[1]

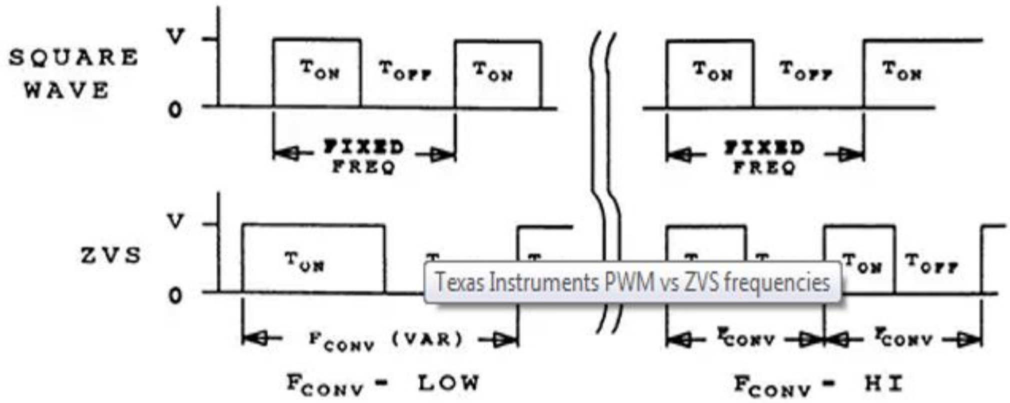

Figure 5 : conventional PWM employs a fixed frequency, but varies the duty cycle to achieve regulation; in contrast, ZVS varies the conversion frequency (which in turn alters the on-time) to maintain output voltage (Courtesy of Texas Instruments).

Two other advantages of ZVS are that it reduces the harmonic spectrum of any EMI (centering it on the switching frequency) and allows higher frequency operation resulting in reduced, easier-to-filter noise and the use of smaller filter components. One downside is that there is no guarantee (particularly at high frequencies) that the MOSFET has dissipated all its energy before being switched off. In the long term this "stored" energy can cause component failure, especially in a fastswitching voltage regulator. Power-module makers overcome this problem by adding a fast body diode in parallel with the switch to make sure all the energy is drained from the transistor (Figure 5).

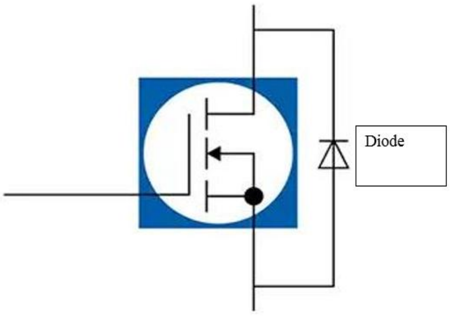

Figure 6: ZVS topologies typically include a fast-body diode in parallel with the MOSFET to ensure all energy is drained from the transistor (Courtesy of Infineon Technologies). Zero-voltage switching action

Figure 8 shows a schematic for a ZVS buck topology. This circuit is identical to a conventional buck regulator except for an added clamp switch connected across the output inductor. The switch is added to allow energy stored in the output inductor to be used to implement ZVS.

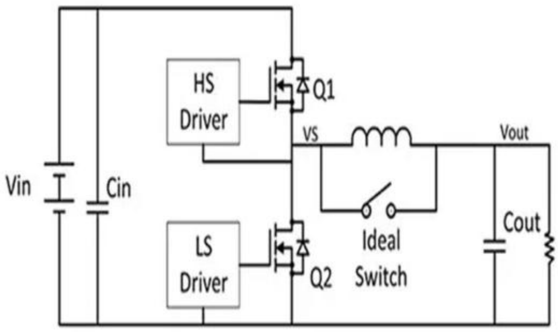

Figure 7: ZVS buck topology (Courtesy of Vicor).

The ZVS buck converter operates in three main states. They are defined as Q1 on phase, Q2 on phase, and clamp phase. Q1 turns on at zero current and when the drain-to-source voltage is nearly zero. Current ramps up in the MOSFET and the output inductor to a peak current determined by the on-time of Q1, the voltage across the inductor, and the inductor value. During the Q1 on phase, energy is stored in the output inductor and charge is supplied to the output capacitor. During the Q1 on phase, the power dissipation in Q1 is dominated by MOSFET onresistance and the switching loss is negligible. Next, Q1 turns off rapidly followed by a very short body diode conduction time (adding negligible power dissipation). During the current commutation to the body diode, Q1 does experience turn-off losses in proportion to the peak inductor current. Next, Q2 turns on and the energy stored in the output inductor is delivered to the load and output capacitor. When the inductor current reaches zero, the synchronous MOSFET Q2 is held on long enough to store some energy in the output inductor from the output capacitor.

Once the controller has determined that there is enough energy stored in the inductor, the synchronous MOSFET turns off and the clamp switch turns on, clamping the VS node to VOUT. The clamp switch isolates the output inductor current from the output while circulating the stored energy as current in a nearly lossless manner. During the (very small) clamp-phase time the output is supplied by the output capacitor. When the clamp phase ends, the clamp switch is opened. The energy stored in the output inductor resonates with the parallel combination of the Q1 and Q2 output capacitances, causing the VS node to ring towards VIN. This ring discharges the output capacitance of Q1, diminishes the gate-to-drain (Miller) charge of Q1 and charges the output capacitance of Q2. This allows Q1 to turn on in a lossless manner when the VS node is nearly equal to VIN.[3]

- Power modules with ZVS

VICOR is a prime example of a company that has embraced ZVS topology. The company has produced a white paper explaining how ZVS works in non-isolated Point-of-Load (POL) buck-regulator applications. The company's Cool-Power ZVS buck regulators form a family of high-density, isolated DC-DC ZVS converter modules integrating controller, power switches, planar magnetics, and support components in a high-density surface-mount package. These power modules are offered in three input-voltage operating ranges; 48 V for communication applications, 28 V for rugged high-temperature applications, and 24 V for industrial applications. The modules are equipped with a variety of programmable features, including output voltage trimming and programmable softstart capability (Figure 9).

Figure 8: Vicor's Cool-Power ZVS buck regulators form a family of high-density, isolated DC-DC ZVS converter modules.

The company claims that ZVS improves efficiency by up to 12 percent compared with competitive devices (Figure 9)

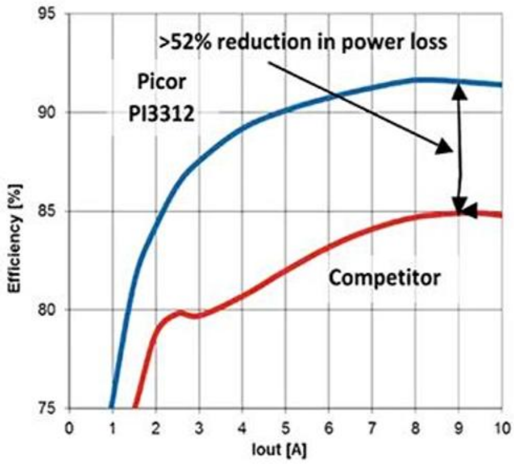

Figure 9: Efficiency curves for Vicor'sPicor PI13312 ZVS topology compared with competitor's device.

Other manufacturers offer modular controllers that can be used for ZVS control strategies for full-bridge convertor ample, Linear Technology supplies the LTC3722 for this purpose. This phase-shift PWM controller provides all of the control and protection functions necessary to implement a high-efficiency ZVS full-bridge power converter. Adaptive ZVS circuitry delays the turn-on signals for each MOSFET independent of internal and external component tolerances. The chip can be used as the basis for voltage regulators with up to 93 percent efficiency. For its part, Texas Instruments (TI) offers a DC-DC switching controller for ZVS regulation, the UCC28950. This controller can implement supervision of a fullbridge converter with active control of the synchronous rectifier output stage. The primary-side signals allow programmable delays to ensure ZVS operation over wide-load current and input-voltage range, while the load current tunes the secondary-side synchronous rectifier switching delays, maximizing system efficiency. Driving up energy density High-density regulators are struggling to keep up with the demands of modern electronic systems primarily due to switching losses hindering performance within the regulator MOSFETs. ZVS addresses these losses and can be applied to most power-conversion designs, but is most advantageous to those operating from a high-voltage input. Significant improvements in efficiency can be obtained in high-voltage, half- and full-bridge ZVS applications when compared to their PWM-controlled equivalents. Moreover, ZVS technology allows the use of switches with lower-voltage ratings, because there is no transient overvoltage, and the reverse voltage applied to the primary switches is limited to the peak input voltage, at most. This frees Upengineers to use components with superior characteristics such as lower conduction losses, lower driving currents, and higher energy density.

II. CONCLUSION

ZVS gives smooth switching as it consist of TRIAC which helps to reduce switching losses hence it meets the significant power demand . ZVS minimize the hard switching losses as during the soft switching V falls to zero before MOSFET turn ON or OFF by eliminating any overlap between V and I and minimize losses and it also minimize the electromagnetic interference . ZVS reduces the harmonic spectrum of any electromagnetic interference and allow the high frequency operation so that it easier to filter noise and the use of smaller filter components .

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