ZVS Flyback Operation

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ZVS Active Clamp Flyback Operation
Simplified Circuit

U.S. Patent: 5,402,329
ZVS Active Clamp Flyback Converter

- Eliminates first order (drain circuit) switching losses for high efficiency and reliability.
- The different ZVS design optimization process enables use of a larger MOSFET die size for reduced conduction losses and higher efficiency.
- Diode reverse recovery effects are eliminated.
- Relatively simple power stage with low parts count compared to all other isolated ZVS topologies.
- Second order transfer function behaves like a standard CCM flyback converter but with improved damping and can accommodate wide line voltage ranges.
- Destined to become an industry standard topology as a higher efficiency and higher frequency alternative to conventional off line flyback converters.
- Simple synchronous rectifier implementation using timing signals from ZVS drive choke. ZVS drive choke can also provide drive power.
ZVS Active Clamp Flyback Operation
Main Switch On Time

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- $M_{\text{MAIN}}$ is on.
- Current (and energy) ramps up in $L_{\text{MAIN}}$ and $L_{\text{ZVS}}$.  

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ZVS Active Clamp Flyback Operation

Turn Off Transition 1

- All switches are off.
- Primary current has reached its peak value.
- During turn off transition voltage rises at nodes A, B, and E.
- Parasitic capacitance of $M_{MAIN}$ and $D_{CLAMP}$ are charged.
- Parasitic capacitance of $M_{AUX}$ and $D_{OUT}$ are discharged.
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Off Time 1

- $M_{AUX}$ body diode and $D_{OUT}$ begin to conduct.
- Node voltages are clamped.
- Primary winding current is still near its peak.
- $I_{SEC1}$ is small compared to $I_{SEC2}$, in general.
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Off Time 2

- \( M_{\text{AUX}} \) turns on immediately after \( M_{\text{AUX}} \) body diode begins to conduct.
- \( V_{\text{NODEA}} > V_{\text{NODEB}} \), \( (V_{\text{NODEA}} - V_{\text{NODEB}}) \) increases with peak current and \( M_{\text{MAIN}} \) duty cycle.
- \( I_{\text{PRI}} \) ramps down gradually to zero.
- \( I_{\text{SEC2}} \) ramps up with ramp down of \( I_{\text{PRI}} \).
- \( C_{\text{RESET}} \) voltage rises and hits a peak when \( I_{\text{PRI}} \) drops to zero volts.

U.S. Patent: 5,402,329
ZVS Active Clamp Flyback Operation

Off Time 3

- $I_{PRI}$ has reversed direction and now ramps up to a negative peak value equal to its original positive peak value.
- $V_{CRESET}$ is falling.
- $I_{SEC2}$ is now much larger than $I_{SEC1}$ and continues to ramp up reaching its peak value at the end of off time 3.
- $V_{NODEA} > V_{NODEB}$

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• \(I_{PRI1}\) had reached its negative peak value.
• \(M_{AUX}\) is turned off.
• Energy stored in \(L_{ZVS}\) charges parasitic capacitance of \(M_{AUX}\) and discharges parasitic capacitance of \(M_{MAIN}\).
• Current in \(L_{ZVS}\) begins to ramp down rapidly as node A voltage falls towards ground.
• Initially node B voltage does not change.
• \(I_{SEC2}\) ramps down as \(I_{PRI1}\) ramps down.
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Turn On Transition 2

- $M_{\text{MAIN}}$ body diode begins to conduct.
- $V_{\text{NODEB}} \gg V_{\text{NODEA}}$
- $I_{\text{PRI}}$ ramps down quickly to zero.
- $I_{\text{SEC2}}$ ramps down rapidly, but does not reach zero yet.

U.S. Patent: 5,402,329
ZVS Active Clamp Flyback Operation

Turn On Transition 3

- $M_{\text{MAIN}}$ is turned on immediately as body diode begins to conduct.
- $V_{\text{NODEB}} \gg V_{\text{NODEA}}$
- $I_{\text{PRI}}$ rapidly ramps down to zero amps then reverses direction.
- $I_{\text{SEC2}}$ continues ramping down rapidly, but does not yet reach zero amps.
- This phase can be considered part of the on time of $M_{\text{MAIN}}$. 
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Turn On Transition 4

- $I_{PRI}$ has reversed direction and is now ramping up in value.
- $V_{NODEB} \gg V_{NODEA}$
- $D_{OUT}$ continues to conduct and $I_{SEC2}$ rapidly ramps down to zero amps.
- This phase can also be considered part of the on time of $M_{MAIN}$. 

U.S. Patent: 5,402,329
I_{SEC2} has dropped to zero and now reversed direction.

D_{OUT} is off and its parasitic capacitance is being charged.

V_{NODEB} and V_{NODEE} are falling, V_{NODEA} = 0

Parasitic capacitance of D_{CLAMP} is being discharged.

I_{LZVS} > I_{LMAIN}, \quad I_{PRI2} = I_{PRI1} + I_{PRI3}

I_{PRI1} contains a component that represents the reflected (through the L_{MAIN} transformer) I_{SEC2} current.

This phase can be considered a part of the M_{MAIN} on time.
ZVS Active Clamp Flyback Operation
Turn On Transition 6

- The node B has dropped to ground forward biasing $D_{\text{CLAMP}}$.
- Without $D_{\text{CLAMP}}$ node B voltage would become negative, ring, and overshoot parasitic capacitance of $D_{\text{OUT}}$.
- $I_{\text{PRI2}}$ remains constant $V_{\text{LZVS}} \approx 0$
- $I_{\text{PRI1}}$ initially drops in value as $D_{\text{CLAMP}}$ turns on because reflected secondary current disappears.
- $I_{\text{PRI1}}$ ramps up gradually due to $L_{\text{MAIN}}$ applied voltage, correspondingly $I_{\text{PRI3}}$ ramps down.
- $D_{\text{CLAMP}}$ continues to conduct until $I_{\text{PRI1}}$ rises to value of $I_{\text{PRI2}}$, $I_{\text{PRI3}} = I_{\text{PRI2}} - I_{\text{PRI1}}$
- This phase of operation can be considered to be part of the $M_{\text{MAIN}}$ on time.