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RESONANCE HELPS BOOST POWER EFFICIENCY

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“Switched-mode power supply (SMPS) topologies have led to advances in efficiency, thanks to continual tweaks and optimisations to circuit designs”

The first step in increasing efficiency in power supply design came with the adoption of the pulse width modulation (PWM) techniques. This concept underpins practically every switched-mode power supply manufactured today, but the initial implementations suffered significant losses.

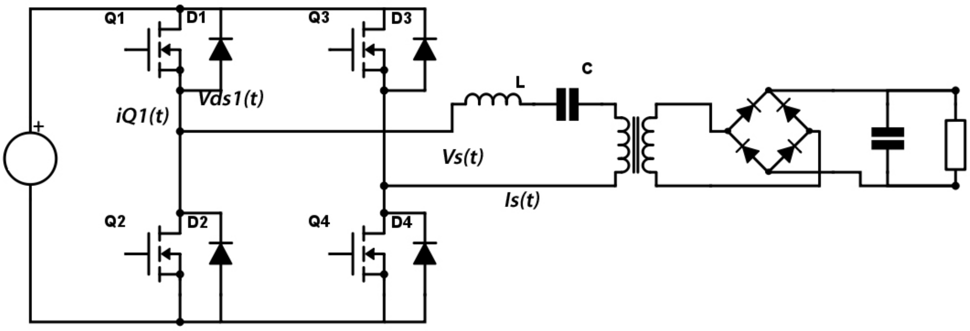
In a half-bridge arrangement with high and low-side MOSFET switches, the PWM converter supplies a regulated output voltage by controlling the on-time of the two transistors. It first turns on the high-side switch. During this on-time, energy is transferred to the output via a transformer, and the output voltage swings upward and current starts to flow in the output inductor. When sufficient energy has been passed to the inductor, the control logic turns off the high-side transistor, and the inductor current then begins to fall. After a delay (which also prevents shoot-through between the two transistors) the low-side switch half-bridge turns on and current in the output inductor starts to increase once more, and so on.

The PWM controller samples the output voltage and compares this to a reference voltage to generate an error signal. An error to the low side indicates that a longer on-time and therefore a higher duty cycle is needed and vice versa. The signal is then usually compared with the output of a ramp oscillator and the result is used to control the duty cycle for the two phases. The continuous adjustment that PWM makes compensates for swings on the input rail and variation in demand from the load. Thereby providing a stable supply of energy to the output load.

Hard Swtiching

The key issue with basic PWM is hard switching – the tactic of turning off the devices while current and voltage are above zero. This switching behaviour can lead to large losses while devices are in a transitional state. The high dV/dt and dI/dt levels encountered during hard switching also lead to considerable electromagnetic interference (EMI). One of the biggest contributions to the surge in efficiency has been the adoption of architectures that make use of resonance. The key to reducing the losses of hard switching is to try to reduce current or voltage to zero or as close as possible before activating or deactivating the power path. Since its development in the 1980s, the main way of implementing this is to move to a resonant architecture.

The resonant architecture takes advantage of reactive passive components in the switching path. Combinations of capacitors and inductors result in frequency resonances that cause the voltage and current to oscillate around a zero point. The simple forms of these are the Quasi-resonant types: in this strategy the voltage across the primary winding is monitored and the switching of the Mosfet is synchronised to a point where current and voltage is at its minimum. This reduces the turn-on switching loss but has little effect on the turn-off.



Schematic of ZCS topology

PMW Swtiching

An early answer was to combine PWM switching with resonant tank circuits, known as soft-switching converters. The switching strategy is dominated by the PWM switching cycle but the voltage and current waveforms are controlled in such a way either is pushed towards zero just before the power transistor switches state. One form is zero-voltage switching (ZVS); the other is zero-current switching (ZCS). Typical ZCS strategies send the current to zero at turn-on and reduce the current as much as possible before turning the transistor back off. The design still incurs losses at turn-on, particularly in MOSFETs because of the capacitive effects in the transistor's body diode.

Another problem associated with ZCS switching is when the transistor starts to turn off or on. At this point a high rate of change of voltage can be coupled to the gate drive circuit through the devices Miller capacitance and this effect can result in the device turning on or off at a slower rate or even bouncing. This is not the case when ZCS is utilised in larger power supply designs based on insulated-gate bipolar transistors IGBTs. In this application a key advantage for the ZCS is encountered. These power transistors tend to suffer from a high tail current when switched off. This is generally due to the high levels of doping needed to build high-power IGBTs. This doping introduces a large number of minority carriers that need to be removed when the device is switched off, which tends to increase the switching time if high current levels are involved. The same effect also tends to limit the maximum achievable frequency when using IGBTs so the switching frequency remains relatively low, which also limits any reduction in size that can be achieved.

In fully resonant architectures the power supply works at close to the circuit resonant point and most controllers run with set duty but have variable a switching frequency as the method of controlling the throughput of energy.

ZVS Swtiching

Resonant ZVS eliminates the capacitive turn-on losses encountered with MOSFETs. The ZVS architecture is similar to that of a conventional PWM converter but, in its simplest form, adds an inductor effectively in parallel with the switch path. The energy stored in the inductor is used to swing the main switching voltage to zero just before turn-on. At turn-off the energy is transferred to the inductor slowing the initial rate of change of voltage so the transistor can be fully switched off before any voltage develops across it. The energy stored in the inductor is also the drawback with this design, as it is not transferred to the output. Instead it circulates from the resonant components back to the input tank.

The resultant reduction in switching losses makes it possible to increase the switching frequency of the conversion circuit, moving from tens of kilohertz to half a megahertz or greater. This can lead to a reduction in the size of transformer, inductors and capacitors, supporting a push towards more compact power supplies. However, there is a problem with the pure resonant architectures. They tend to push high peak power levels though the output path and can have high circulating currents in the resonant components, which places a limit on size reductions as well as leading to higher conduction losses through the active and passive devices.

Synchronous outputs are one of the other areas that have helped achieve better overall efficiencies. In this system the output rectification is handled by Mosfets synchronised to the PWM switching and turned on at the same point a diode would be conducting current. A small amount of dead time is always included, as any misalignment will lead to shoot through and significant losses. The advantage of synchronous rectification is that the voltage drop across the devices when passing current is less than the voltage that would be present across a diode when conducting.

Trade-offs

The reduction of losses in both the turn-on and turn-off stages has allowed switching frequency to increase, This, combined with reduction in overall losses, has resulted in reductions in power supply size for a given wattage. Since the development of the original quasi-resonant and ZVS, ZCS strategies, a number of variants have been developed, each lending itself to different applications. For example, the phase-shifted topology in a full-bridge AC/DC converter has successfully yielded supplies able to deliver 10kW of power at an efficiency of more than 95 per cent.

Although some of the tradeoffs between topologies are easy to see, such as the differences between ZCS and ZVS in high-power designs based on IGBTs and size versus efficiency, others are more complex. Such subtleties can lead to large differences in efficiency, reliability and cost and make it worth consulting with power-design experts on the best way forward.