DESIGNING OPTIMAL MULTI-OUTPUT CONVERTERS WITH A COUPLED-INDUCTOR CURRENT-DRIVEN TOPOLOGY

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Abstract

This paper examines the relative merits of several topological approaches to the design of multiple-output switching power converters. A design approach using a coupled-inductor current-driven (CICD) buck regulator topology is developed, with emphasis on the optimal design of the coupled inductor in order to minimize its leakage reactance.

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1. INTRODUCTION

Transformer-coupled boost converter topologies with multiple outputs have inherently good cross regulation. Serious disadvantages of boost-derived converters are their discontinuous output current which puts a great burden on the output capacitors, and the right-half plane zero in their control characteristic when operated in the continuous conduction mode.

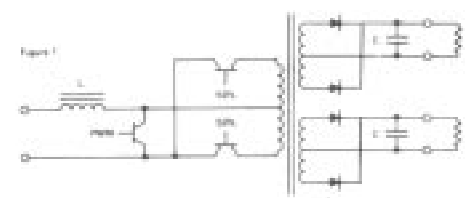
Conventional transformer-coupled buck converters with multiple outputs have poor cross regulation and suffer from current spikes associated with their inherent low impedance (voltage-driven) input circuits.

A unique buck-derived converter topology employing an inductor whose primary winding is on the input side of the transformer and secondary winding(s) on the output side (1),(2) combines most of the advantages of conventional buck <u>and</u> boost topologies with few of the disadvantages of either.

2. TOPOLOGICAL COMPARISONS

2.1 THE BOOST CONVERTER

A transformer-coupled boost converter is shown in Figure 1. It is often implemented by omitting the shunt pulse-width modulated transistor, achieving modulation control by means of deliberate overlap in the conduction of the two push-pull transistors. During the interval of conduction overlap, the transformer primary is shorted, thereby charging the input inductor and decoupling the output.



Output voltages of the boost converter are related to the input voltage as follows:

$$V_{out} = V_{in}(N_S/N_P)/(1-D)$$

Duty cycle, D, is the ratio of the "on" time of the PWM transistor (or time of conduction overlap) to the total period., N_S/N_P is the ratio of secondary to primary turns.

2.1.1 Advantages.

__Current limiting.__ The boost converter is **current-driven** because the series input inductor acts as a high impedance source at high frequencies, thereby providing dynamic input current limiting. This prevents the current spikes that would otherwise be associated with momentary short circuits caused by events such as transformer core saturation, slow rectifier recovery, or transistor conduction overlap.

__Continuous input current.__ Because of the series inductor, input current is continuous with very moderate rates of change. This results in simpler input filtering and reduced EMI.

__Low peak voltages.__ Peak voltages on the transformer secondaries are equal to the output voltages (neglecting rectifier drops and leakage reactance spikes), regardless of the line input voltage level. Excess input voltage is dropped across the input inductor. Transformer utilization is good because maximum volt-seconds are limited and independent of input voltage. Rectifier PIV requirements are only 2 times their respective output voltages, regardless of input voltage.

__Good cross-regulation.__ There are no filter inductors in series with each output to impair cross-regulation. Series resistances of rectifiers and transformer secondaries are usually quite small, but rectifier forward recovery characteristics must be very good. Output voltages will then relate to each other in almost exact proportion to the ratio of secondary turns, virtually independent of load currents, provided leakage inductances between secondaries and wiring inductances are minimized.

2.1.2 Disadvantages.

__Discontinuous output current.__ During the "on" time of the shunt transistor, current provided to the output capacitor ceases abruptly. The output capacitor must provide all of the load current during the "on" time, without assistance. This places a severe requirement on both the series inductance and ESR of the capacitor. For this reason, the boost configuration is seldom used in low voltage, high current output applications. During the "off" time, rectifier peak current levels are much larger than DC load current levels. These problems are also characteristic of flyback converters.

__Difficult control loop optimization.__ As Middlebrook has shown, the control-to-output transfer function of the boost converter (as well as the flyback converter) operated in the continuous conduction mode has a right-half plane zero. This causes considerable difficulty in optimizing the feedback loop to obtain the desired gain and dynamic response together with good loop stability. (3)

2.2 THE BUCK CONVERTER

The full-wave center-tap transformer-coupled buck converter with multiple outputs shown in Figure 2 is, together with its half-bridge counterpart, the most widely used configuration for off-line converters.

Output voltages of the buck converter are related to the input voltage and the duty cycle:

$$V_{out} = V_{in}(N_s/N_p)D$$