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Soft-Switched Interleaved Buck Converter with Closed Loop Control

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***Abstract**: Design, modeling and simulation of a closed loop control system exhibits its function on an interleaved buck converter with soft switching. Among the features of the closed loop system there exist two fundamental benefits: reduced switching losses together with parallel-connected converter current sharing. Owing to PWM technology the control system for the converter receives its design structure. Dynamic stability and transient response improvement in the converters relies on current mode control-based controller parameters.*

The parallel operation between zero current switching converters functions because of resonant components that maximize efficiency while minimizing voltage and current oscillation. MATLAB/Simulink serves as the platform for analyzing and designing and running performance tests of the system. The actively controlled system demonstrates fast dynamic behavior in its operation through a PID controller design process that can be observed in simulation tests. A PIC16F877A microcontroller serves as the foundation when developing the Buck converter lab prototype to verify the controller platform.

***Keywords**: Buck converter, resonant component, microcontroller, interleaved, and zero current switching*

I. Introduction

The most efficient power electrical device for transforming unregulated dc input voltage into regulated dc output voltage is the switched mode dc-dc converter. The design of switched mode power supplies surpasses that of linear power supplies because they produce more compact systems with higher efficiency and density. The extensive application of switched mode dc-dc converters enables the delivery of diverse dc outputs for personal computers along with computer peripherals and communication equipment and medical electronic equipment apart from consumer adapters. Buck converters represent the top dc-dc converter configuration used across portable consumer devices.

All dc-dc converters show characteristics as time-invariant nonlinear dynamic systems. All three elements of inductors, capacitors and switching power devices exist as main nonlinear origins throughout dc-dc converter operation. Large passive components form the basis of buck converters except for being their most essential flaw. When the switching frequency increases the converter loses efficiency by triggering multiple losses that reduce efficiency especially during low-power operation. Multiple soft switching techniques serve as technical solutions to bypass this problem [1]. Zero voltage and zero current switching methods which constitute soft switching strategies result in substantial reduction of switching losses and lead to increased converter efficiency.

Zero-current switching helps achieve three main benefits according to this study's main topic: (i) The inductor current remains at zero before each new switching cycle starts thus improving efficiency and (ii) Zero-current switching forces the inductor to start charging with zero current thus limiting peak current to exactly twice the average value. By using zero current switching the inductor automatically begins charging at zero current thus defining its peak current to be exactly double the average current value. The desired outcome exists for steady states as well as switch cycle relationships that occur instantly.

II. Closed Loop Control System for DC

The closed loop control system for the ZCS Interleaved Buck converter with PID controller feedback is shown in the Figure 1

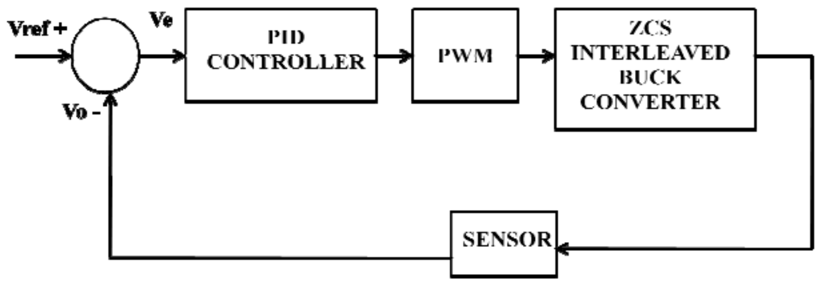

Fig 1: closed loop control of dc-dc controller

A PID controller works alongside PWM (Pulse Width Modulation) for implementation in a dc-dc converter system through Figure 3 to achieve error minimization between V. The PID Controller adjusts error signal (V_e) to operate as c. The driver signal originates from the compensator through PWM block generation. The compensator block applies PID Controller logic to compute Ve by comparing V_o to V_{ref} to make a control signal. The controller tuning characteristics belong to the essential elements of control systems because the control signal significantly influences the converter operation.

III. Simulation Results

The combined output of the Buck converter and interleaved one operates at a 12V level throughout input transients that reach 44V, 46V and 48V. The output voltage in Figure 2 reaches equilibrium much faster which enhances the converter's dynamic operational characteristics. The responses display both smooth undershoots and overshoots. The output voltage maintains an almost perfect smoothness level. The current distribution between L1 and L2 shows perfect equality as shown in Figure 3 which supports one of the key controller design advantages.

Simulation results show that the PID controller produces the most precise results when comparing simulated to mathematical values for the ZCS Interleaved Buck converter as depicted in Figure 4. All requirements for the converter were established when it was developed across the time dimension. In this operating point neither overshoot nor undershoot occurs while the controller achieves output voltage control for similar voltage transients within an accelerated settling time. The converter stage successfully preserves current equalization between the inductors.

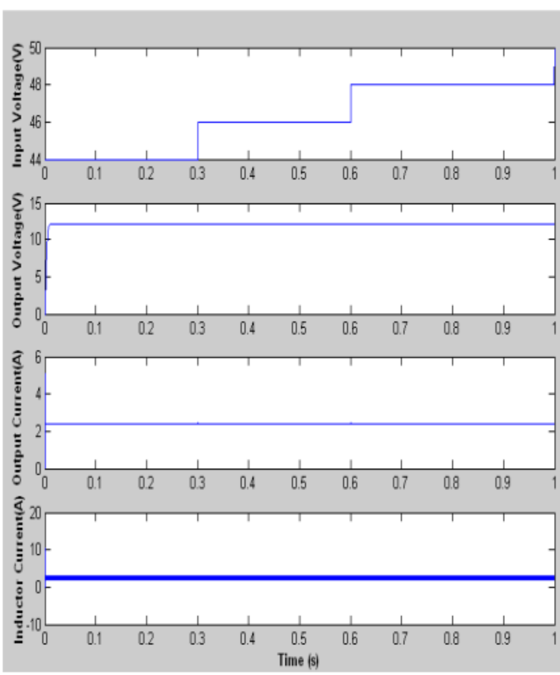

Fig 2: Simulation results for Buck converter

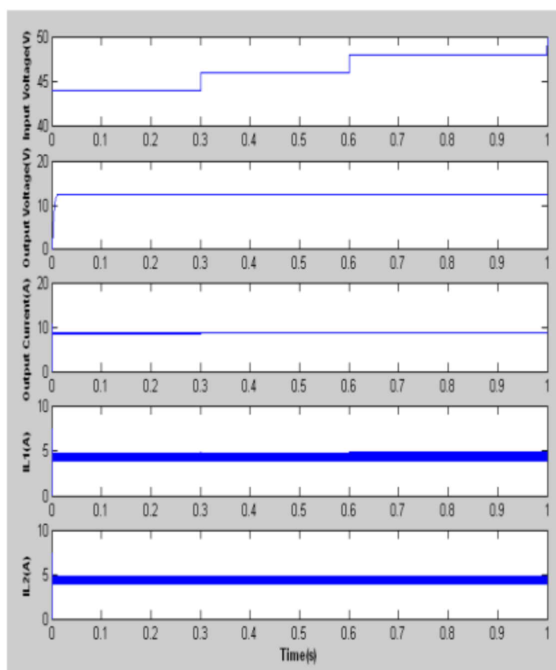

Fig 3: Simulation results for Interleaved Buck Converter

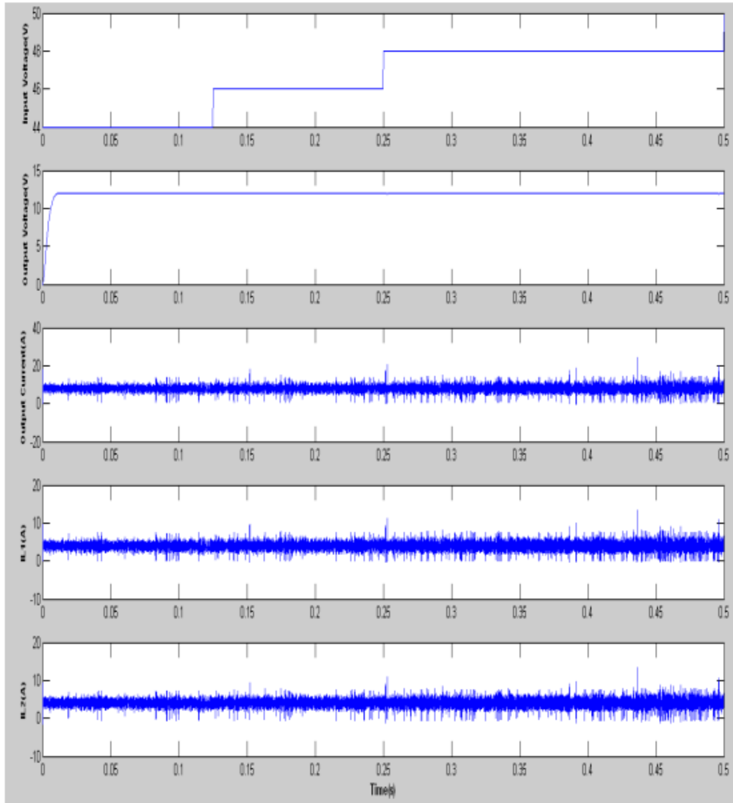

Fig 4: Simulation results for ZCS Interleaved Buck Converter

The output current exhibits some ripple that needs optimization according to Figure 4. The figures in Figure 5 illustrate the output voltage assessment of the three converter stages. The waveforms enter their steady-state condition from zero-point beginning while reaching peak values during steady-state operation. The Buck converter waveform settles down first among all three stages during specific time periods. Testing demonstrates that the dynamic performance improved throughout all stages which confirms the straightforward nature as well as robust and efficient implementation of the generated controller solution.

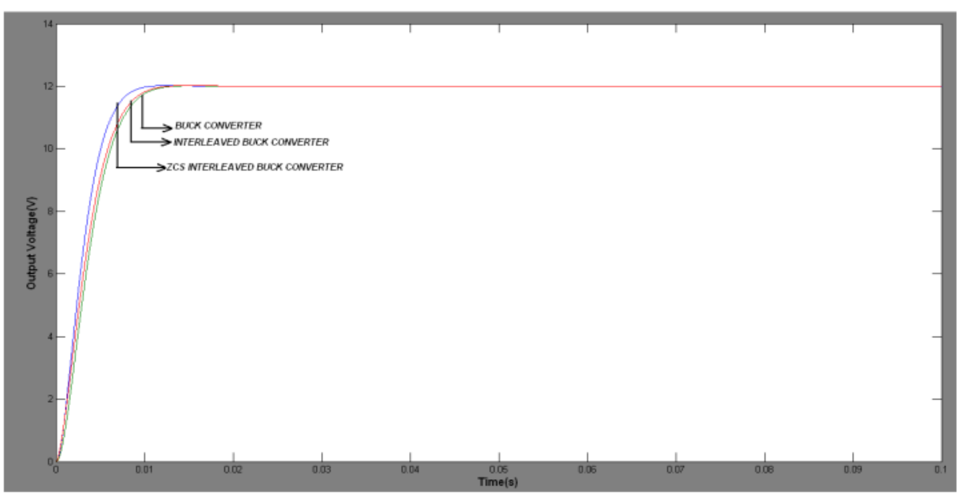

Fig 5: Output Voltage Comparison for the three stages

Figure 6 displays the efficiency of the ZCS Interleaved Buck Converter, Interleaved Buck Converter, and Ordinary Buck Converter against the load current.

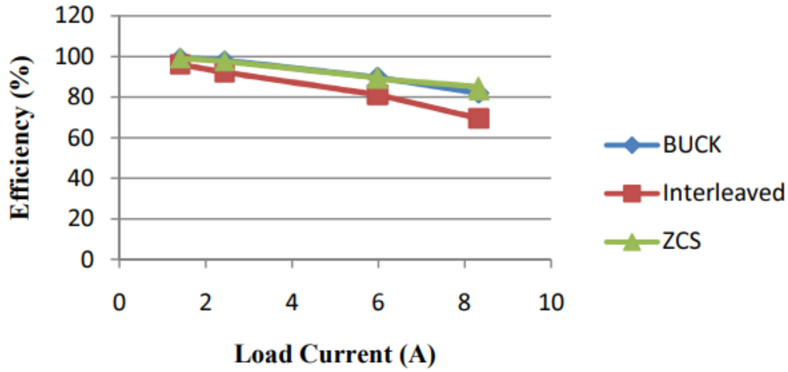

Fig 6: Comparison of Efficiencies

IV. Conclusion

The ZCS Interleaved Buck converter received its closed loop control system design through implementation of a PID controller operating in continuous time domain. The evaluation between MATLAB/Simulink simulation data and mathematical computational results leads to similar findings. The PIC16F877A works as the control platform that executes the controller designed for the Buck converter leading to experimental results. The created controller reaches tight output voltage control together with enhanced dynamic functions and better efficiency levels according to testing and modeling results and mathematical studies.

With a load value of 1.44Ω, the soft switching that is therefore used results in the highest efficiency of 98% by lowering switching stress and losses. Good current sharing between the Buck converters connected in parallel is made possible by the controller. This technique can be expanded for any application, including speed control, solar cell, and power factor reregulation, and it is topology independent. The microcontroller-based prototype is easier to implement, more efficient, and more suited for portable electronic devices.

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