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Variable Frequency Digital PWM Control for Low-Power Buck Converters

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Abstract—*This paper describes digital pulse width modulation (DPWM) controller technique for implementing low-power buck converters. The converter is operated at Discontinuous conduction mode to reduce the losses during switching. A DPWM controller is developed to achieve the best possible transient performance under load current change. Simulation of the converter is carried out using MATLAB/SIMULINK and the results indicate that it has good dynamic performance under load change.*

I. INTRODUCTION

Advanced power management technique relies on integration of power control and conversion functions with digital systems [1-4]. Passive component count can be greatly reduced due to the programmable features. Sensitivity to process and parameter variations is insignificant in digital controllers. Control schemes that are considered impractical for analog realizations can be realised. [5].

While implementing a sophisticated control algorithm the sampling rate of the analog to digital - converter (ADC) is reduced by a factor of ten to achieve a high efficiency comparable to analog-controlled converters. A high computing power is not involved which is the precondition for a high overall efficiency of a low-power converter. In this project, a variable frequency DPWM controller for low-power buck converters is presented. The converter is designed to operate at DCM and found to have potential to reduce switching losses The DPWM based buck converter is studied using MATLAB/SIMULINK.

As the buck converter operates in the discontinuous conduction mode (DCM) the switching losses are reduced and the efficiency is increased [6]-[8].

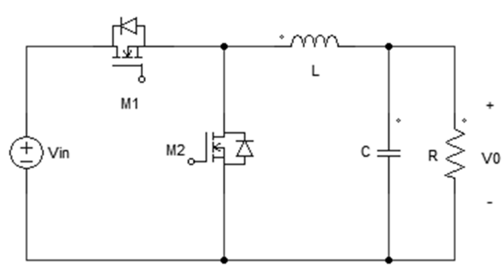

Fig-1. Circuit diagram of Buck Converter

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The DPWM is incorporated into the buck converter for closed loop operation. Line and load regulation performance comparable to a constant frequency DPWM is ensured through control rules for changing the switching frequency. A comparison of open loop buck converter and DPWM controlled buck converter is made with respect to their transient response using MATLAB-SIMULINK.

II. Digital PWM Controller

Drastic reduction of system costs and power is possible through digital control of analog circuits [9-14]. Many microcontrollers and DSPs already include on-chip PWM controllers, making implementation easy. PWM is a way of digitally encoding analog signal levels. Through the use of high-resolution counters, the duty cycle of a square wave is modulated to encode a specific analog signal level. The PWM signal is still digital because, at any given instant of time, the full DC supply is either fully ON or fully OFF. The voltage or current source is supplied to the analog load by means of a repeating series of on and off pulses. The on-time is the time during which the DC supply is applied to the load, and the off-time is the period during which the supply is switched off. Given a sufficient bandwidth, any analog value can be encoded with PWM.

An Analog to Digital Converter (ADC) is a very useful feature that converts an analog voltage on a pin to a digital number. By converting from the analog world to the digital world, we can begin to use electronics to interface to the analog world around us.

The analog signal is continuous in time and it is necessary to convert this to a flow of digital values. It is therefore required to define the rate at which new digital values are sampled from the analog signal. The rate of new values is called the sampling rate or sampling frequency of the converter.

A proportional integral-derivative is control loop feedback mechanism used in industrial control system. In industrial process a PI controller attempts to correct the error between a measured process variable and desired set point by calculating and then giving corrective action that can adjust the process accordingly. The PI controller calculation involves two separate modes the proportional mode and integral mode. The proportional mode determine the reaction to the current error, integral mode determines the reaction based recent error. The weighted sum of the two modes output as corrective action to the control element. PI controller algorithm can be implemented as

where e(t) = set reference value – actual calculated.

III. Buck Converter

A buck converter is a voltage step down and current step up converter. The simplest way to reduce the voltage of a DC supply is to use a linear regulator (such as a 7805), but linear regulators waste energy as they operate by dissipating excess power as heat. It operates in Continuous Conduction Mode. The relationship between the input voltage (Vs) and the output voltage (Vo) is given as,

$$d = \frac{V_o}{V_s} = \frac{T_{ON}}{T_S}$$

where d is the duty-cycle, TON is conducting time of the switch and Ts is the switching period. The switching period Ts can be expressed as,

$$Ts = \frac{I_L V_s}{V_o(V_s - V_o)}$$

where ΔI is the ripple current, L is the inductance of the circuit.

The value of L can be determined from,

$$Lf_s \, I_L = V_s \, d(1-d)$$

The capacitor C is then determined by the allowed voltage ripple ΔVc. The ripple voltage is given as,

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$$V_c = \frac{V_s d(1-d)}{8LC\, f_s^{\ 2}}$$

The value of capacitance depends on the change in the load.

A. State Variable Modelling

The state-space averaging is an approximate technique that can be applied to describe the input and the output relation of a buck converter. All state variables are subscribe dx˙'s and all sources are subscribed as u's.

The state equation method as follows,

$$\dot{x} = A_1 x + B_1 u$$

$$\dot{x} = A_2 x + B_2 u$$

where,

$$\dot{x} = Ax + Bu$$

where x is a state vector, u is a source vector, A1, A2, B1, B2 are the state coefficient matrices.

$$A = dA_1 + (1-d)\, A_2$$

$$B = dB_1 + (1-d)\, B_2$$

where d is the duty cycle.

B. Optimal Switching Frequency

Losses, which occur at buck converters, have to be examined to determine its optimal switching frequency. Our converter permanently operates in the discontinuous conduction mode (DCM)[15]. Furthermore, the synchronous buck converter is forced to work in DCM due to the dramatically reduction of the switching losses. In theory, the inductor current is zero at the beginning and at the end of a switching period in DCM.

Thus, no switching losses arise during turning on the high-side transistor and during turning off the low-side transistor. The same holds true for turning on the low-side transistor because the voltage drop over the transistor is zero. This means, remarkable switching losses only occur during turning off the high-side transistor. This will affect the efficiency negatively, if the switching frequency fsw rises. The gate charge losses also have a negative influence on the efficiency with increasing switching frequency.

IV. Simulation Results

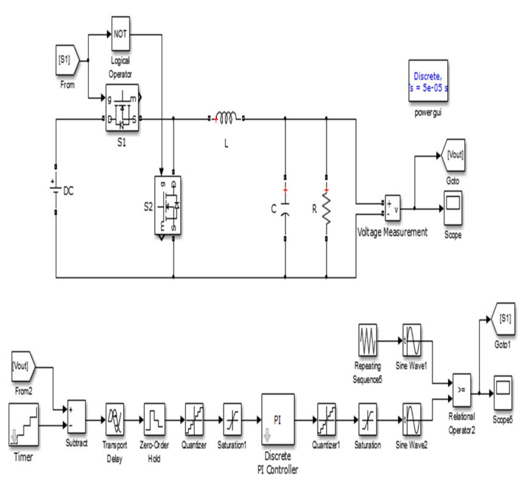

Fig-2. Simulation block diagram

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PARAMETERS	VALUES
Battery voltage	100 V
Output voltage	80 V
Proportional gain of controller	.001
Integral gain	.01
Coil inductance	1 µH
Coil resistance	50 Ω
Capacitance	750 Mf
esr	1 Ω
Switching frequency	Variable
Resolution of ADC	12 bits
Quantization step voltage	1 mV
Sampling rate of ADC	100 kHz
Delay of ADC	7 µs

Table 1. Simulation parameters

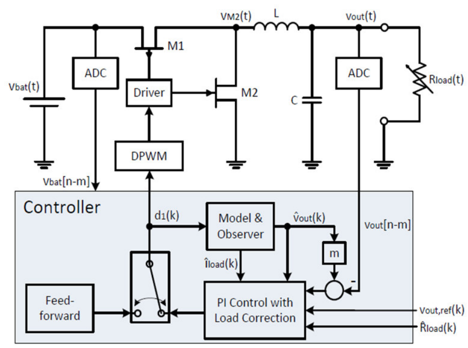

Fig 3. Functional Block Diagram

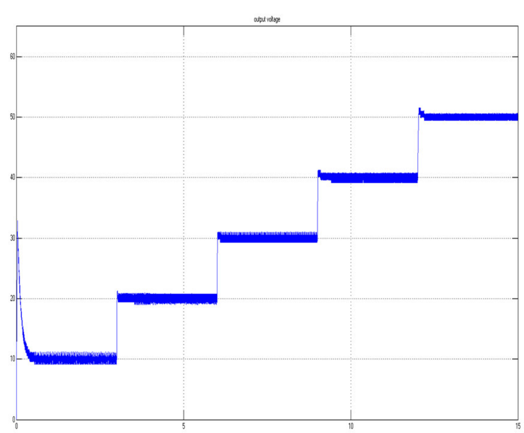

Fig-4. Output voltage

V. Conclusion

The proposed digital PWM is implemented in a low-power buck converter controlled by UCD9220. It is shown that the proportional and integral gains of a PI controller can be selected based on the input error signal value to significantly improve the dynamic response

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of the buck converter. The DPWM controller exhibits a similar performance to a constant switching frequency DPWM while minimizing switching losses.

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