Research Paper

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Comparison of System Model and Mathematical Model of Open-Loop Buck Converter

Engineering

KEYWORDS : Buck converter, Open loop, system Model, Mathematical Modelling

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ABSTRACT

This paper presents the design and simulation of system model and mathematical modelling of an open loop buck converter.The dc-dc converter converts an unregulated dc voltage to a constant or regulated voltage. However the converter values changes with time and temperature [1]. Hence to control the output voltage, it is required to understand the dynamic behavior and transient response of the converter, which can't be understood by the system model of the converter. So one of the way to model by mathematical modeling, defined by set of differential equations [1]. This paper represent the mathematical modeling of a pulse width modulated (PWM) open loop buck converter and its verification by simulation in SIMULINK.

I. Introduction

A buck converter is the most basic non isolated SMPS topology. It can convert input voltage source into a lower regulated voltage. It is used in laptop computers, dc motor drives, industry where it is required to step down the voltage and those applications require fast load and line transient responses and high efficiency over a wide load current range [4]. Ideally, the dc-dc converter exhibits 100% efficiency, but practically it exhibits 70% to 95% efficiency. This is achieved by switched-mode circuits whose elements dissipate negligible power. Control and regulation of the total output voltage is achieved by Pulse-width modulation(PWM).

II Buck Converter

The name "Buck Converter" comes from the fact that the input voltage is bucked/chopped lower voltage appears at the output [2]. Buck converter also known as step down converters produce an average output voltage lower than the input voltage.In the buck converter circuit, MOSFET is used as a switch, is switched at high frequency to produce a chopped output voltage. This voltage is then filtered by series LC circuit known as filter circuit to produce a smooth load voltage at output voltage Vo. The output voltage is controlled by the duty cycle D, which is given by:

$$Vo = Vi \times D \quad \text{.....(1)}$$

Where,

$$D = \frac{Ton}{Ton+Toff}$$

Average output voltage is LESS than Input Voltage. There aretwo ways to vary the average output voltage [3]:

First the Pulse Width Modulation (PWM), where ton is varied while the overall switching period T is kept constant and secondly by Pulse Frequency Modulation (PFM), where ton is kept constant.

While the switching period T is varied the buck converter operates in two mode: continuous mode and discontinuous mode.

In continuous Conduction Mode (CCM) Inductor current remains positive throughout the switching period and in Discontinuous Conduction Mode (DCM) Inductor current remains zero for some time in the switching period.

Pulse-width modulation (PWM) is used to achieve the control and regulation of the total output voltage in which the control voltage (reference voltage) is compared to a triangular voltage [1] and the switch Q is controlled according to the difference between this voltage.

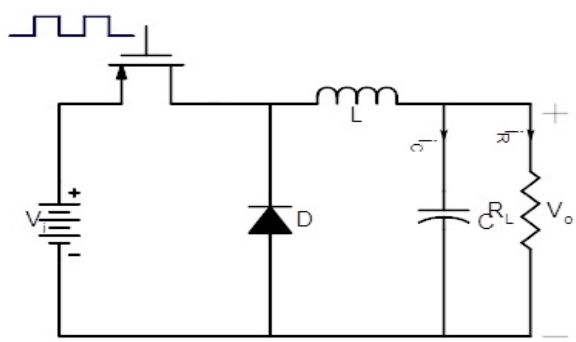


Fig 1: Basic Buck converter circuit

III. Modelling of Open-Loop Buck converterIn Simulink

In order to build the buck converter model in Simulink it is required to decide parameter. Table 1 shows the parameter specification required to model buck converter.

Table 1 Specifications

Topology	Buck Converter
DC input voltage (Vi)	100V
Output voltage (V_o)	50V
Switching Frequency (F_s)	50KHZ
Output current (i_L)	2.4A
Output voltage ripple (ΔV)	0.5V
Output current ripple (ΔI)	0.72A
Maximum Power (P_{max})	120W

1) System Model of Buck Converter

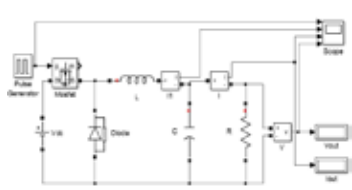


Fig 2: Model of Buck Converter in Simulink

(2) Mathematical Modelling of Buck Converter

The differential equations are [1]:

$$V_i(t) = V_o(t) + \frac{L di_L(t)}{dt} \ldots\ldots\ldots\ldots (2)$$

$$i_L(t) = \frac{1}{L}\int (V_i(t) - V_o(t))dt \ldots\ldots (3)$$

$$V_o(t) = \frac{1}{C}\int i_C(t)dt \ldots\ldots\ldots\ldots\ldots (4)$$

Applying KCL and KVL in the Fig. 1 we can get

$$i_C(t) = i_L(t) - i_R(t) \ldots\ldots\ldots\ldots (5)$$

$$i_C(t) = \frac{C dV_C(t)}{dt} \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$V_o(t) = \frac{1}{c}\int i_L(t)dt - \frac{1}{c}\int \frac{V_o(t)}{R}dt \ldots(7)$$

Since the buck converter is a switching device having two states of operation while working in CCM are taken into account using a logical variable F, can have two values 0 and 1 is given in Table 2.

TABLE 2: PWM Control Logical Variables

T	D	F
On	Off	1
Off	On	0

Now,

$$V_L(t) = (V_i(t) - V_o(t)) * F - V_o(t) * \bar{F} \ldots (8)$$

This is the state equation of buck converter represents the mathematical model of the buck converter which is simulated in Simulink. The PWM logic of buck converter is implemented in Simulink as shown in Fig 3.

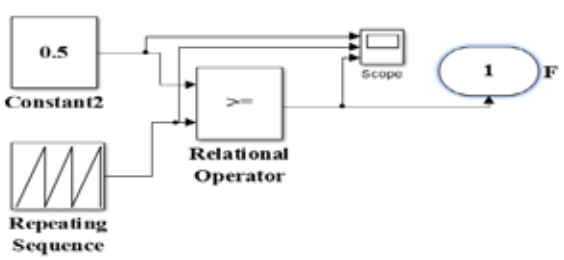


Fig 3: PWM Block of Simulink Buck Model.

The equation (2) to (8) are used to design the buck converter as shown in fig.4.

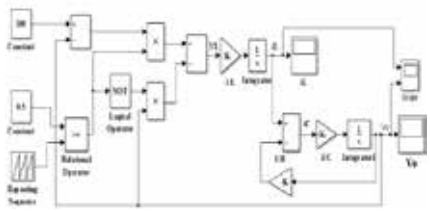


Fig 4: Mathematical Model of Buck Converter in Simulink

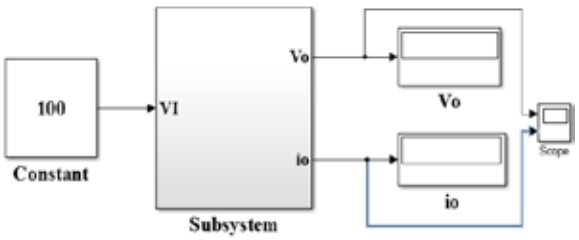


Fig 5: Subsystem of complete Buck Converter Circuit.

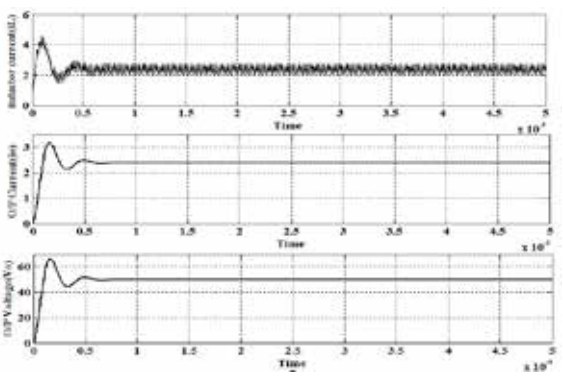


Fig 6: Response of Open-Loop Buck converter
Waveform 1: Inductor Current Waveform
Waveform 2: Output Current Waveform
Waveform 3: Out voltage Waveform

Table 3. Comparison of System and mathematical model

	System Model	Mathematical Model
Output Voltage	49.51V	49.99V
Output Current	2.38A	2.042A

IV. Conclusion

After simulating the system model and mathematical model of buck converter, waveforms so obtained are in acceptable agreement .From the Table 3 the simulation response results of mathematical model is gives more accurate value than system model. This open loop modeling can also be used for closed loop modeling.

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