Design and Control of Buck Converter using PI control and Reference Regulator Technique

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Abstract— In paper proposes about DC-to-DC buck converter design and control of output voltage by using a PI control technique and reference regulator technique. DC-DC converter is a power electronics circuit, which converts one voltage value to another. Buck converters are step-down converters, where output voltage is lower than input voltage. Buck converter topology is used in this paper with the controlled output voltage by the PI control and reference regulator technique. Voltage in this type of converters controlled through switching by storing energy in circuit and releasing it afterwards to output at given voltage level. In this paper input voltage is 100V, output voltage is obtained is 50V by the simulation model results. Considered: R = 100 ohm (90 ohm for testing under higher load) R2 = 900 ohm connectable resistance $L = 10^{-6}$H $C = 5x10^{-6}$ F PI controller: P = 2 , I = 310, Frequency of switching is 200 kHz values This conversion method is more efficient than voltage division, where unwanted power dissipated as heat. First two parts of this paper introduces design analysis of the circuit in Simulink. Third part includes stress test experiments in order to verify specifications.

KEYWORDS: *DC-DC Converter, BUCK Converter, Reference regulator and switcher, PI-Control)*

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I. Introduction

In many industrial applications it is required to convert a fixed voltage dc source in to a variable dc source. A dc-dc converter converts directly from dc to dc and is simply known as dc converter. A dc converter can be considered as dc equivalent to an ac transformer with a continuously variable turn's ratio. Like a transformer it can be used to step down or step up a dc voltage source. The buck converter is the most widely used for traction motor control in electric automobiles, trolley cars, marine hoists, forklift trucks, and mine haulers. They provide smooth acceleration control, high efficiency, and fast dynamic response. Buck converter is also called as step down. It means the output voltage is less than the input voltage[1] Dc converters can be used in regenerative braking of dc motors to return energy back in to the supply, and this feature result in energy savings for transportation systems with frequent stops. Dc converter are used in Dc voltage regulators and also are used in conjunction with an inductor to generate a dc current source especially for the current source inverter[2,3]. The transistor switching loss increases with the switching frequency and as a result the efficiency decreases. In addition the core loss of inductors limits the high frequency operation. Control voltage vc is obtained with a sawtooth voltage vr to generate the PWM control signal for the desired value. The Vcr can be compared with a four basic topologies of switching regulator [4,5] Dc-Dc converter topology in power management and microprocessor voltage-regulator (VRM) applications. Those applications require fast load and line transient responses and high efficiency over a wide load current range. They can convert a voltage source into a lower regulated voltage. For example, within a computer system, voltage needs to be stepped down and a lower voltage needs to be maintained. For this purpose the Buck Converter can be used[6]. Furthermore buck converters provide longer battery life for mobile systems that spend most of their time in "stand-by". Buck regulators are often used as switch-mode power supplies for baseband digital core and the RF power amplifier (PA) [7] In a buck regulator the average output voltage Va is less than the input voltage, Vs hence the name buck a very popular regulator. [8]. Novel control of voltage control and current control mode operation is performed [9]. The name "Buck Converter" presumably evolves from the fact that the input voltage is bucked/chopped or attenuated, in amplitude and a lower amplitude voltage appears at the output. A buck converter, or step-down voltage regulator, provides non-isolated, switch-mode dc-dc conversion with the advantages of simplicity and low cost. A simplified non-isolated buck converter that accepts a dc input and uses pulse-width modulation (PWM) of switching frequency to control the output of an internal power MOSFET. [10] An external diode, together with external inductor and output capacitor, produces the regulated dc output. Buck, or step down converters produce an average output voltage lower than the input source voltage [11].

II. OPERATING PRINCIPLE OF BUCK CONVERTER

Buck converter is also called as step down converter. It means the average output voltage is less than the input voltage. Figure .1 shows the circuit diagram of a buck converter. Here the power semiconductor devices is IGBT. The LC filter is used to the reduce the ripple content. The operation of buck converter is divided in to two modes.

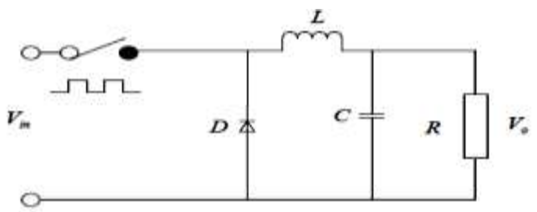


Figure. 1 Buck converter circuit diagram

A. MODE : 1

When the switch is turned on by applying pulse signal from control unit. The switch may be a BJT, IGBT or a power MOSFET. At instance of time t=0 the switch comes to ON state and now the current flow through switch , inductor L, capacitor C, and load. During the ON time of the switch we can get the output voltage and inductor current increases from I_1 to I_2. The voltage across the inductor $V_L = V_{in} - V_o$

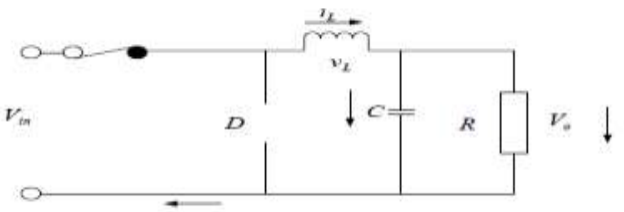


Figure. 2 Mode 1 operation of Buck converter ON state

B. MODE : 2

In the mode operation when the switch position changed from ON to OFF state the pulse signal of the switch is zero. During the OFF position of the switch the freewheeling diode comes to conducts due to stored energy in the inductor and now the inductor current flows through Inductor L, Capacitor C, Load L, and freewheeling diode. During this period inductor current decreases from I_2 to I_1. Now the voltage across the inductor is $-V_o$. Inductor current reaches to I_1 again switch is turned ON. The inductor current could be continuous and discontinuous depending the switching frequency, filter capacitance and inductance.

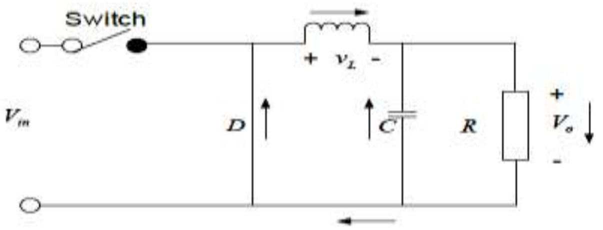


Figure. 3 Mode 2 operation of Buck converter OFF state

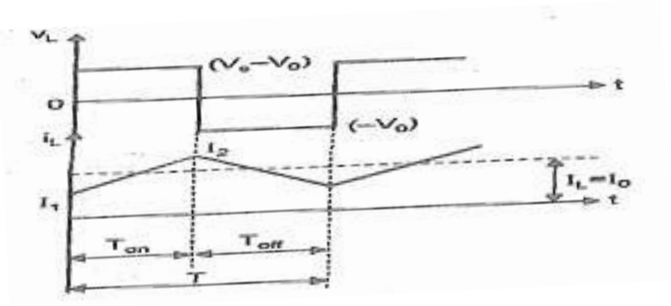


Figure. 4 Waveforms of Voltage and current

III. DESIGN SPECIFICATION OF BUCK CONVERTER

To design DC to DC converter one method of converter is used Buck converter. Buck converter should be controlled and match the specifications design and converter should resistant to change the load and reference voltages. The buck converter should meet the desired range of specifications frequency switching ranges from 100KHz to 300 KHz and the inductor values specification range from 0.001 mH to 10mH and the capacitor ranges from 0.001mF to 3mF voltage ripple should be 1% and current ripple of 1%.

Voltage across the inductor L

$$V_L = L.\frac{di}{dt} \tag{1}$$

$$V_s - V_o = L.\frac{\Delta I}{T_{ON}} \tag{2}$$

$$T_{on} = L.\frac{\Delta I}{V_s - V_o} \tag{3}$$

$$\Delta I = \frac{(V_s - V_o)T_{on}}{L} \tag{4}$$

During the off period of switch the inductor current falls linearly from I_2 to I_1.

$$-V_o = -L.\frac{\Delta I}{T_{off}} \tag{5}$$

$$T_{off} = \frac{\Delta I.L}{VT_o} \tag{6}$$

$$V_o = \alpha V_s \tag{7}$$

Average source current

$$I_s = \alpha I_o \tag{8}$$

For the design values of buck converter. Input voltage Vin is 100 output voltage should be controlled and the voltage should be step down to desired value. Vin =100V value of Inductor $L=10^{-6}$H, capacitor value C=5 μF, and frequency is 200KHz. Value of resistance is 100 Ω

$$F_{resonant} = \frac{1}{2\pi\sqrt{LC}} = 71.176\ KHz. \tag{9}$$

Duty cycle by varying the duty cycle of the switch the average ouput voltage is varied.

$$D = \frac{Vo}{Vs} = 0.5 \tag{10}$$

$$R_{max} = \frac{2.f.L}{1-D} = 0.8\,\Omega \tag{11}$$

$$L_{min} = \frac{(1-D).R}{1-f} = 0.125mH\ \Omega \tag{12}$$

$$P = \frac{Vo2}{R} = 25W. \tag{13}$$

IV. SIMULATION MODEL

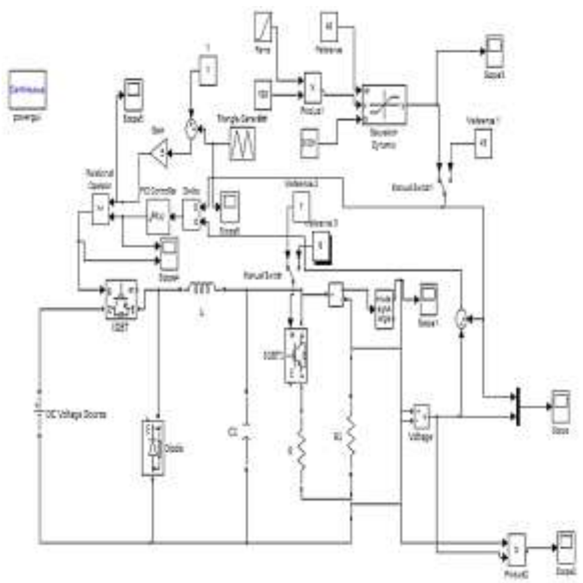
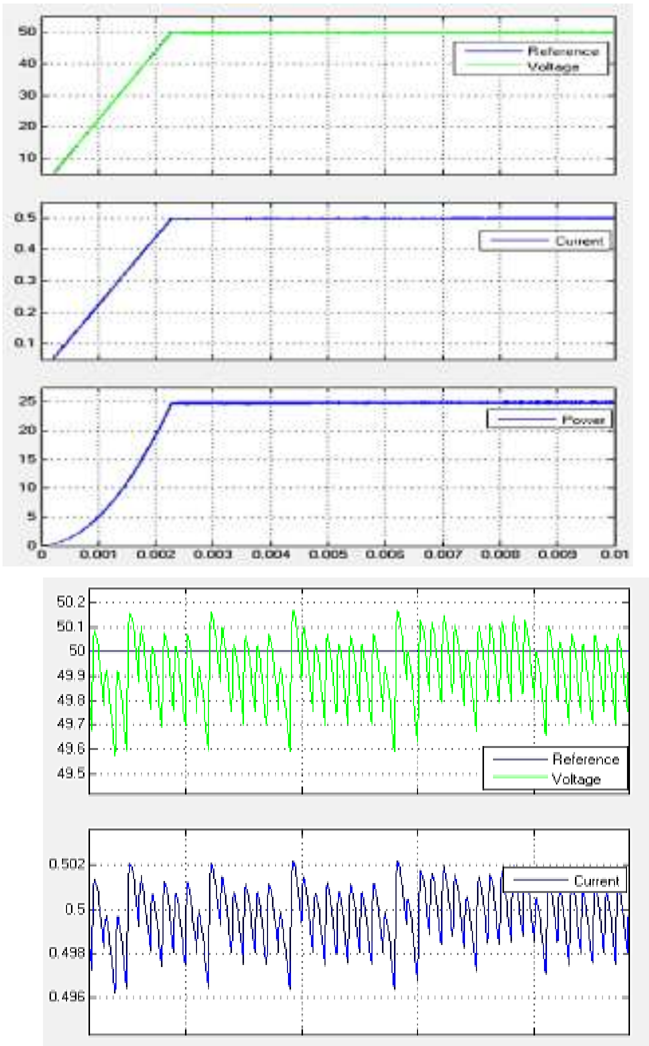


Figure. 5 Matlab simulation model of Buck converter

Dc voltage source for this simulation circuit is 100V .IGBT, controlled by PI controller used in this paper in order to control the output voltage. Here the Switch allows current to pass to fill energy in capacitor and inductance. Diode used for accumulated energy during charged state to pass in order to energize load. In this paper, following values for RLC considered: R = 100 ohm (90 ohm for testing under higher load) R_2 = 900 ohm connectable resistance and inductance $L = 10^{-6}$H $C = 5x10^{-6}$ F are implemented in the Matlab model design. In oder to control the desired output voltage implementing PI controller technique Following PI values obtained after tuning PI controller: P = 2 ,I = 310. Triangle wave generator used for generating frequency for switching between on and off states. Frequency of switching is 200 kHz. Reference regulator and switcher in order to avoid overshooting at the very beginning of circuit operation ramp voltage referencing considered. By doing so, voltage increases at rate of 22.1 V/ms without overshoots. For example, circuit goes from 0 V to 40 V in 1.8 ms without any overshoot. Additionally, reference switcher allows to switch voltage on the fly. ramp reference voltage introduced in order to avoid overshooting.

V. ANALYSIS OF RESULT

As we calculated before, we need 50% duty cycle in order to keep 50V on output with 100V input. However, it is not the case in open-loop mode, because we have energy storing elements, which pumps up output voltage almost to 100V. That is why we need to consider closed-loop control. Obtained results demonstrate, that closed loop control is better, in general and allows significantly better control In other words, closed-loop results match specifications mentioned before input is 100V output is 50V and current is 0.5A and power rating is 25W.



.Figure. 6 Result of closed loop control

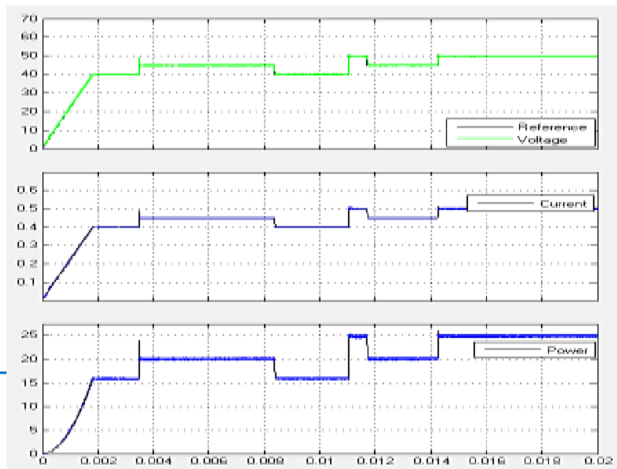


Figure. 7 Voltage and current ripple is 1% and 0.8% ranges.

The output result of Fig 7 demonstrates that voltage and current ripple stays in 1% and 0.8% range, respectively

Figure 8 Output result of reference change with different Voltages

In the figure 8 shows the ouput results of referenc echange with different voltages. In this test, reference changes by given path (40V 45V 40V 50V 45V 50V).This results demonstrate, that system is capable to change its reference voltage without any dangerous behaviour and overshoots

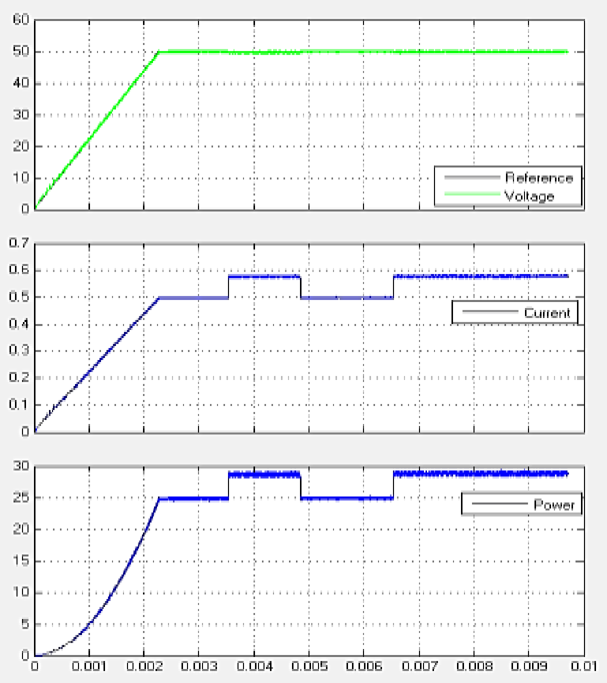


Fig .9 Stress test Load change from 100 ohms to 90 Ohms

In this stress test, system tested on its behaviour of load change from 100 ohms to 90 ohms (50V reference). Results given in From the graphs it can be seen, that circuit behaves very adequately to changed reference by adaptation to changes

VI. CONCLUSION

This paper implies the design process of the DC-to-DC BUCK converter. In the analytical solution of the problem, design process, simulation details, stress tests and experiments were discussed. As it can be seen from the results of the experiments, controller fulfill given tasks and shows good results for given specifications. In addition, controller and the circuit is able to perform under extreme and dynamic conditions, i.e. when the power increased dramatically or reference changed. Moreover, some additions such as ramp reference voltage introduced in order to avoid overshooting.

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