Design, Control and Simulation of Buck Converter using PID controller and Reference Regulator Technique

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Abstract— In this paper explains about DC-to-DC buck converter design and control of output voltage by using a PID control technique and reference regulator technique and circuit testing with different change in resistance value. Buck converters are step-down converters, where output voltage is lower than input voltage. DC-DC buck converter is a power electronics circuit, which converts one voltage value to another value with step down level. Voltage in this type of converters controlled through switching by storing energy in circuit and releasing it afterwards to output at given voltage level. Buck converter topology is used in this paper with the controlled output voltage by the PID control and reference regulator technique and testing of the circuit with changing different resistance value. This conversion method is more efficient than voltage division, where unwanted power dissipated as heat. In this paper input voltage is 200V, output voltage is obtained is 100V by the simulation model results. Considered: R = 120 ohm (90 ohm for testing under higher load) R2 = 980 ohm connectable resistance L = 10^{-6}H C = $6x10^{-6}$ F PID controller: P = 2 , I = 310, D = 400. Frequency of switching is 300 kHz values. First two parts of this paper introduces design analysis of the circuit in Simulink. Third part includes stress test experiments verifying with changing in different resistance value 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 used to convert a fixed voltage dc source in to a variable dc source. Like a transformer it can be used to step down or step up a dc voltage source A dc converter can be considered as dc equivalent to an ac transformer with a continuously variable turn's ratio. A dc-dc converter converts directly from dc to dc and is simply known as dc converter. The buck converter is the most widely used for traction motor control in electric automobiles, mine haulers, marine hoists, trolley cars, forklift trucks. Buck converter is also called as step down. 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. They provide smooth acceleration control, fast dynamic response high efficiency, and. It means the output voltage is less than the input voltage. Dc converters 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. 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 saw tooth 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. DC-DC converter topology in power management and microprocessor voltage-regulator (VRM) applications. They can convert a voltage source into a lower regulated voltage. Those applications require fast load and line transient responses and high efficiency over a wide load current range.

In a buck regulator the average output voltage Va is less than the input voltage, Vs hence the name buck a very popular regulator. Buck regulators are often used as switch-mode power supplies for baseband digital core and the RF power amplifier (PA). Furthermore buck converters provide longer battery life for mobile systems that spend most of their time in "stand-by". For example, within a computer system, voltage needs to be stepped down and a lower voltage needs to be maintained. Novel control of voltage control and current control mode operation is performed. 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. 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. 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. Design is tested by using stress test by different level of resistance values from 100 ohm to 900 ohm resistance values.

II. OPERATING PRINCIPLE OF BUCK CONVERTER

Buck converter is also known as step down converter because it converts the average output voltage is less than the input voltage. Figure.1 shows the circuit diagram of a buck converter. The LC filter is used to the reduce the ripple content. The diode will act as a freewheeling mode. Here the power semiconductor devices are IGBT switch is used here. The operation of buck converter is divided in to two modes.

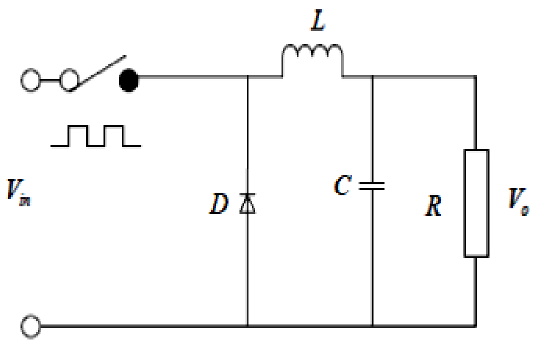

Figure. 1 Buck converter circuit diagram

A. MODE : 1 Operation Switch ON Statte

The switch may be a BJT, IGBT or a power MOSFET. The switch (IGBT) is used it can be turned on by applying suitable pulse signal from control unit. The switch is turned ON At instance of time t=0 the switch comes to ON state and now the current flow through switch and then current flow through inductor L, and passes through capacitor C, and then to the load side. Capacitor is used to charge and discharge. During the ON time of the switch we can get the output voltage and inductor current increases from I_1 to $I_{2.}$ $_{\text{Vin to V out.}}$ The voltage across the inductor **$V_L = V_{in} - V_o$**

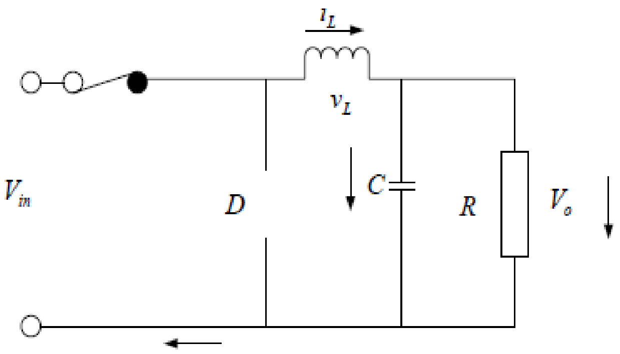

Figure. 2 Mode 1 operation of Buck converter ON state

B. MODE : 2 Operation Switch OFF Statte

In this mode of operation switch is 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 current flow through the diode 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.

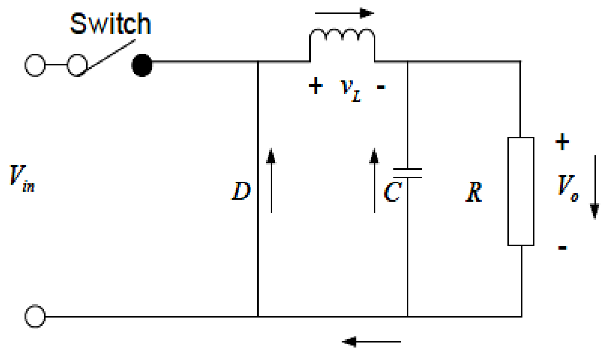

Figure. 3 Mode 2 operation of Buck converter OFF state

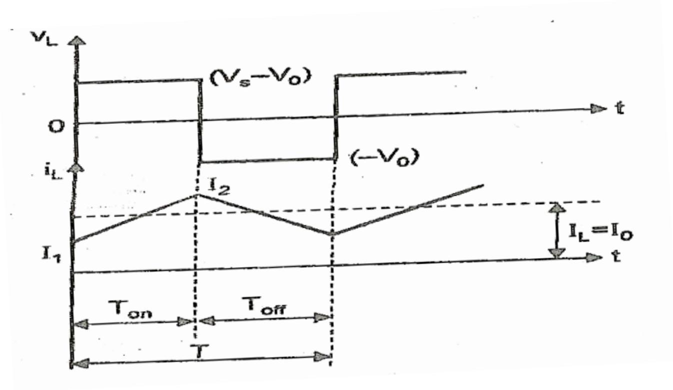

Figure. 4 Waveforms of Voltage and current

In Figure 4 waveform explains the output waveform with respect to output load voltage and output load current where IL=Io.. During TON the output current increases and during TOFF the load current gets decreased. Total Time = TON + TOFF

III. DESIGN SPECIFICATION OF BUCK CONVERTER

Buck converter should be controlled and match the specifications design and converter should resistant to change the load and reference voltages. To design DC to DC converter one method of converter is used Buck converter. The buck converter should meet the desired range of specifications frequency switching ranges from 100KHz to 400 KHz and the inductor values specification range from 0.001mH to 20mH and the capacitor ranges from 0.001mF to 5mF voltage ripple should be 0.9% and current ripple of 0.9%.

Voltage across the inductor L

$$V_L = L.\frac{di}{dt} \quad (1)$$

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

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

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

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

$$-V_o = -L.\frac{\Delta I}{T_{off}} \quad (5)$$

$$T_{off} = \frac{\Delta I.L}{VT_o} \quad (6)$$

$$V_o = \alpha V_s \quad (7)$$

Average source current

$$I_s = \alpha I_o \quad (8)$$

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=5μF, and frequency is 200KHz. Value of resistance is 100 Ω

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

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

$$D = \frac{Vo}{Vs} = 0.5 \quad (10)$$

$$R_{max} = \frac{2.f.L}{1-D} = 0.8\ \Omega \quad (11)$$

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

$$P = \frac{Vo2}{R} = 25W. \quad (13)$$

IV. SIMULATION MODEL

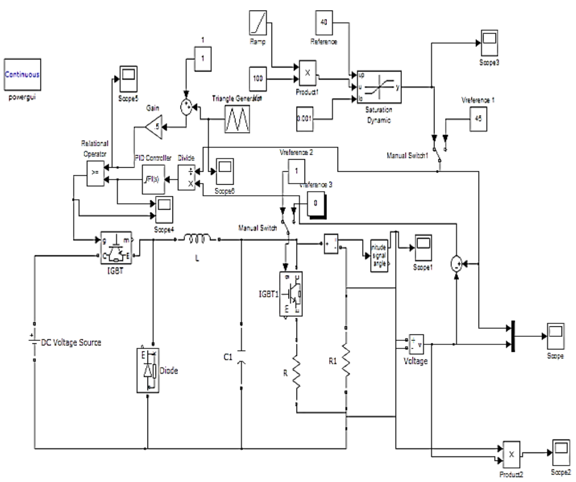

Figure.5 Matlab simulation model of Buck converter PID Controller

Dc voltage source for this simulation circuit is 200V .IGBT, controlled by PID 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 = 200 ohm (90 ohm for testing under higher load) R2 = 990 ohm connectable resistance and inductance L = 10^{-6}H C = $6x10^{-6}$ F are implemented in the Matlab model design.

In order to control the desired output voltage implementing PID controller technique Following PID values obtained after tuning PID controller: P = 2 ,I = 310. D= 400. 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 33.1 V/ms without overshoots. For example, circuit goes from 0 V to 50 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. SIMULATION WAVEFORM RESULT

It is calculated that we need 50% duty cycle in order to keep 50V on output with 100V input. Current is obtained as 0.5 However; it is not the case in open-loop mode, because we have energy storing elements, which pumps up output voltage almost to 110V. 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 51V and current is 0.5A and power rating is 25W. The output results are obtained by using the simulation output waveform with input of 100V and output of the Buck converter is 50V the voltage is step down to half value. And current value is 0.5 and power rating is 25W

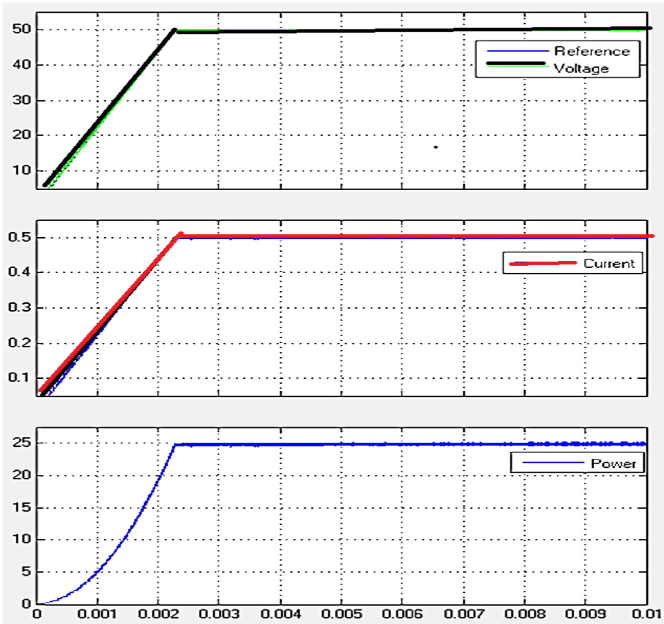

Figure. 6 Result of closed loop control

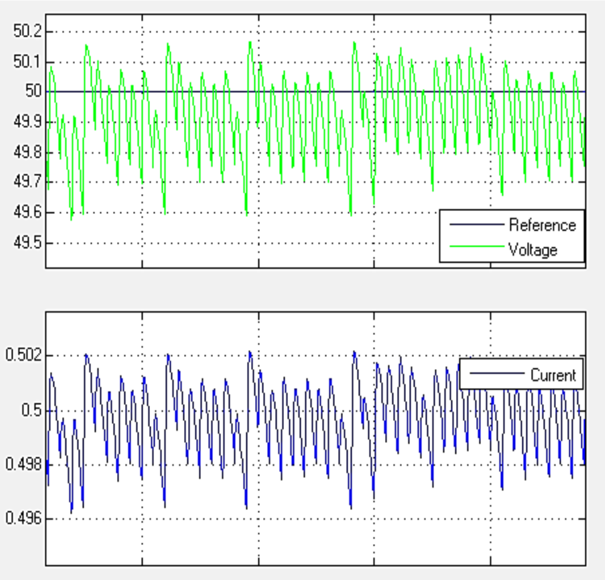

Figure. 7 Voltage and current ripple is 1% and 0.8% ranges.

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

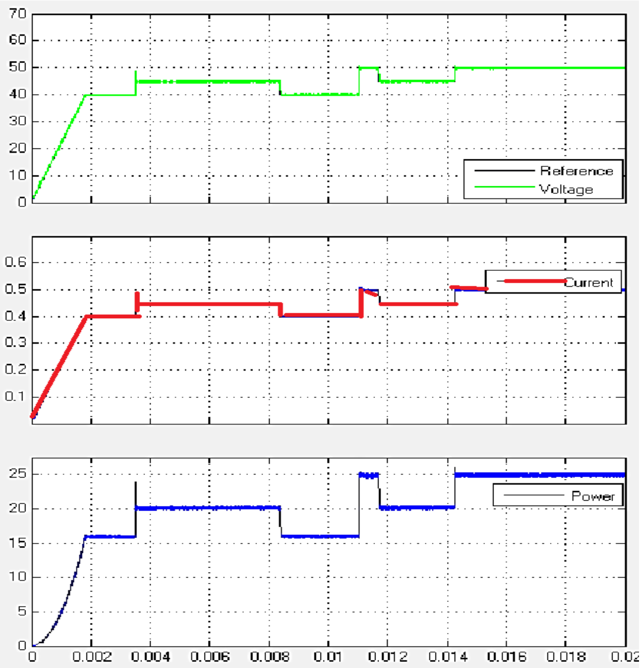

Figure 8 Output result of reference change with different Voltages

Figure 8 waveform shows the ouput results of referenc exchange with different voltages. In this test, reference changes by given path (40V to 45V to 40V to 50V to 45V to 50V).This results demonstrate, that system is capable to change its reference voltage without any dangerous behaviour and overshoots. The Waveform describes the overshoot change in different voltage level in voltage, current and Power.

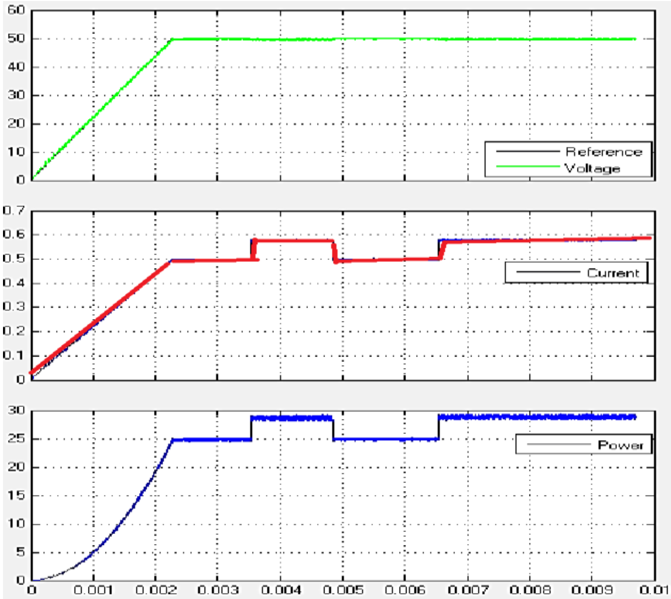

Fig .9 Stress test Load change from 100 ohms to 990 Ohms

In this stress resistance change test, system tested on its behaviour of load change from 100 ohms to 990 ohms (50V reference). Under the testing the by changing the values of the resistance the there are small deviation in the voltages and current and power waveform result. The peak raise and fall Results given in From the graphs it can be seen, that circuit behaves very adequately to changed reference by adaptation to changes. The circuit changes the value of resistance and adapts to its same point.

VI. CONCLUSION

This paper proposes the design process of the DC-to-DC BUCK converter simulation model and testing of the circuit 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. By using the circuit we can design with input values and we can cross verify the different output voltages and different currents and power ratings. By varying the resistance values from 100ohm to 990ohm the voltage and current changes with different values. 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. The design of buck converter circuit can be used in led driver circuit applications. By varing the voltage levels the different output values are obtained.

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