Simulation and Hardware Implementation of DC-DC Buck Converter for Higher Energy Transfer in the field of Renewable Energy

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Abstract— With the advancement of electronic industry the requirement of low power supply is essential as numerous industrial and commercial devices rely on power converters for regulated and reliable DC power source. The demands of DC-DC converters are increasing exponentially because of their high efficiency, small size as well as simple architecture. The complexity in modelling of DC –DC converter mainly depends on its usage and its sophistication as it ranges from simple analogue design for low cost application to digital and self-adaptive model for better performance. This paper comprises of method for obtaining the small signal model of DC-DC buck converter by linearizing it using state space averaging technique. Both state space as well as non-linear model of Buck converter is the simulated in MATLAB and desired response is observed.

Keywords— DC-DC Buck Converter, 555 timer, TLP-250(isolator), MATLAB(SIMULINK), PROTEUS ISI 8.7

I. Introduction

Conventional energy sources like coal, gas, etc. make a remarkable contribution towards the production of energy in India. The problem associated with the above mentioned energy sources is the cause of ongoing research in order to find the suitable alternative. Environmental pollution and lack of sources in case of conventional one are being the stepping stone for the energy extraction from the renewable energy sources like solar, wind, tidal, geothermal, etc. Researchers are working hard to enhance the figure of merit of such integrated system of energy in order to improve the efficiency of energy extraction. Power electronic dc-dc converter plays an important role to boost the voltage to such a level such that energy extraction can be maximized in solar system. BUCK converter is the most efficient and reliable dc-dc converter among all the available converters due to its high efficiency, voltage boosting capability, less ripple both in input and output side, inherit presence of filters, low cost etc.

Focus of this paper is to model a controlling system for buck converter which controls output of buck converter and keeps it constant instead of changing circuit parameters, load and input supply of the buck converter. This is a nonlinear converter, which has faster response in transient condition[1]. This paper presents the DC-DC converter model, implementation and simulation using state space modeling approach. The simulation computation time has improved up to 7.8 times faster as compared to circuitry model[2]. This paper proposed a DC-DC buck boost converter which mainly presents the downbeat lower output voltage than the input voltage. It consists of same elements similar to a conventional DC-DC buck converter such as MOSFET switch, paired inductors and switched capacitor. A PSIM simulation has been conducted to compare and contrast the efficiency of the proposed DC-DC buck boost converter and conventional DC-DC buck converter. The result shows the efficiency of the proposed DC-DC buck boost converter is higher than the conventional DC-DC buck converter in terms of both switching frequency and load variation[3]. In recent days, dc-dc power converters are gaining more attention in the power electronic research field. To meet the various level of voltage demand, single input and multiple output topologies (SIMO) are developed. Many such converter topologies are available under this category. Integrated Dual Output Converter (IDOC) is one of the single input multi output topologies. IDOC is a DC-DC power converter which performs both buck and boost operations at the same time with a single power supply. IDOC is derived from the conventional boost converter using couple of power switches. With the shoot through phenomenon both the switches in the IDOC can be connected in series and operated to obtain the boost and buck voltage simultaneously.

In this paper, the basic operation of IDOC is presented and compared with conventional buck and boost converter. The hardware prototype model of IDOC with 100W is developed and tested. Also the experimental results are compared and verified with the simulation results. Also the performance comparison among buck, boost and IDOC converter is done and presented [4]. The simplicity of the proposed algorithm provides fast and high quality tuning of optimum PID controller parameters effectively. From simulation results, the proposed method compared to the genetic algorithm was found more efficient in improving the transient response of Buck converter[5]. The mathematical modelling of nonlinear, switched open loop PWM
controlled buck converter has been presented. The simulation response results of physical and mathematical model were in excellent agreement, confirming,[6]. A switched-inductor semi-quadratic buck converter is a modification of two-switch semi-quadratic fifth-order buck converter which belongs to the minimum-phase family. An L -switching structure is combined with the semi-quadratic buck converter in order to get high voltage conversion ratio. Moreover, it gives more bucking than the semi-quadratic buck converter. The superiority of the proposed converter is mainly based on less energy stored in the inductors. The current stress in the switching elements is less, which results in lower conduction losses. Salient performance features like voltage bucking, switching stress, inductor current etc. of proposed converter is compared with that of a semi-quadratic buck converter. In this work, simulations of both the buck topologies are presented and these are done using MATLAB/Simulink software. A prototype of 5W, 20 kHz switched-inductor semi-quadratic buck converter is designed, analyzed and implemented using PIC16F877A[7].

II. BUCK CONVERTER

Suppose we have to power an LED strip from the same 3.3V rail. LEDs easily consume around 20mA each, so a long strip would easily eat up an amp or so. If we calculate the power dissipated by the regulator:P = (Vin – Vout) * Iout. The power dissipated comes out to be around 8.7 Watts! Now this is a LOT of power for a little linear regulator to dissipate. If we calculate the efficiency, which is just output power divided by the input power, it comes out to be a pathetic 38%!. Normally Linear voltage regulators has very low efficiency compared with switching regulators. Now we feel the pressing need to find something that can step DC voltages down and do it efficiently! The buck converter is designed with filter element like inductor and capacitor. When converter is in working state, MOSFET and Diode work in complimentary to one another i.e when Diode is ON, MOSFET is OFF and when MOSFET is ON, Diode is OFF. This happens at the rate of switching frequency. The working of Buck converter is slightly similar to that of PWM ‘dimming’. We’ve all heard of lights being dimmed by a PWM signal. A small duty cycle means that the average voltage seen by the load is small and when the duty cycle is high the average voltage is high too.

But average voltage is not what we need – a raw PWM signal oscillates between high voltage level and ground, something no delicate load (like the microcontroller) would like. Of course, connecting an RC filter to a square wave source renders the output clean. The voltage level of the filter depends on the duty cycle of the PWM signal – the higher the duty cycle the higher the output voltage.

III. Operation

The power circuit diagram of buck converter with equivalent circuit diagram of both ON & OFF mode is shown in figure 1.1.

The working of a buck converter can be broken down into a few steps.

STEP – 1: The switch turns on and lets current flow to the output capacitor, charging it up. Since the voltage across the capacitor cannot rise instantly, and since the inductor limits the charging current, the voltage across the cap during the switching cycle is not the full voltage of the power source.
STEP – 2:
The switch now turns off. Since the current in an inductor cannot change suddenly, the inductor creates a voltage across it. This voltage is allowed to charge the capacitor and power the load through the diode when the switch is turned off, maintaining current output current throughout the switching cycle.

These two steps keep repeating many thousands of times a second, resulting in continuous output.

IV. Mathematical Modelling

The differential equations related to state variables are:

\[ (t) = V_0(t) + L \frac{di(t)}{dt} + rL \frac{d}{dt} \frac{i(t)}{L} \] (1)

\[ (t) = \frac{1}{L} \int (V_i(t) - V_0(t) - rL \frac{i(t)}{L}) \] (2)

\[ V_0(t) = \frac{1}{C} \int i_C(t) \, dt + i_C(t) \cdot rC \] (3)

Applying KCL and KVL in the figure 1 we can get

\[ i_C(t) = (t) - iR t \] (5)

\[ i_C(t) = C \frac{dV}{dt} \] (5)

\[ (t) = V_0(t) - rC \frac{i(t)}{C} \] (6)

\[ V_0(t) = \frac{1}{C} \int i_L(t) \, dt - 1 \int \frac{V_0(t)}{R} \, dt + rC \frac{i(t)}{C} \] (7)

The state equations of the buck converter considering the parasitic resistances of filter inductance and capacitor given by equation (2) and (7).

V. SIMULATION

Implementation of proposed strategy is done in MATLAB environment. The parameters for simulation were varied and corresponding changes were observed.
The parameter taken for doing simulation and verification of waveform is given in the table:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inductor</td>
<td>3mH</td>
</tr>
<tr>
<td>Capacitor</td>
<td>470uF</td>
</tr>
<tr>
<td>PWM Frequency</td>
<td>15KHz</td>
</tr>
<tr>
<td>Input Voltage</td>
<td>15 Volts</td>
</tr>
</tbody>
</table>

VI. 555 Timer circuit

555 timer circuit is essential for proving gate pulse to the switch and it is being simulated in PROTEUS isolated and then configured to the power circuit of Buck converter.
The simulated waveform is shown in below and it is observed that pulse is varied with time and square in nature with constant pulse width time.

![Simulated Output of 555 timer using PROTEUS ISI 8.7](image)

VII. **Hardware implementation**

In first step the hardware implementation of 555 timer circuit is done which is shown below

![Hardware implementation of 555 timer](image)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance(R1,R2)</td>
<td>220 Ohm</td>
</tr>
<tr>
<td>Resistance(R3,R4)</td>
<td>390 Ohm</td>
</tr>
<tr>
<td>Capacitance(C1)</td>
<td>1uF</td>
</tr>
<tr>
<td>Capacitance(C2)</td>
<td>1nF</td>
</tr>
<tr>
<td>IC chip</td>
<td>NE555</td>
</tr>
<tr>
<td>Battery</td>
<td>9Volt</td>
</tr>
<tr>
<td>LED</td>
<td>4V,2A</td>
</tr>
</tbody>
</table>
VII. CONCLUSION

In this paper the concept of higher energy extraction and application in the field of renewal energy using BUCK converter to it are discussed briefly. In this paper MOSFET is being chosen as a switch for hardware implementation of the propose converter. The drivesignal for the switch is being generated by TLP 250 at afrequency of 15KHz. Output current of the BUCK converter at a fixed load which is continuous and the output voltage had very less ripple.

REFERENCES