REAL TIME PERFORMANCE ANALYSIS OF BUCK DC-DC CONVERTER

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Abstract: Buck converter high side switching configuration can affect substantial reduction in power converter performances, allowing considerable higher power losses. This paper investigates a buck topology that achieves improved perfomance of direct current dc-dc buck converter by increasing duty cycle and by selecting low side switching configuration to reduce the power losses . The performance of buck converter for both high side switching configuration and low side switching configuration is analyzed. The design of buck converter circuit are investigated. The experimental results demonstrate the feasibility and high performance of the dc- dc buck converter. The analysis is verified experimentally using LVDAC - EMS.

Keywords*- Buck Converter, Data Acquisition and control interface. LVDAC- EMS.*

1. INTRODUCTION

The demand for high efficiency DC-DC converters is increasing dramatically, especially for use in battery-operated devices such as cellular phones and laptop computers. In these devices, it is intrinsic to extend battery life. By employing DC-DC converter power-saving techniques, power efficiency can be significantly increased, thereby extending battery life[1].Switching power con-verters inherently generate ripple, and typically require output filtration to meet ripple and EMI specifications. The buck type switched dc to dc converter is well known in power electronics. Due to the fact that the converter con-tains two energy storing elements, a coil and a capacitor, smooth dc output voltages and currents with very small current ripple can be generated [6].Buck converter has two types of switching configurations. One is low side switching configuration of buck converter and other is high side switching configuration. The Low side switching configuration is preferred instead of high side switching configuration, as it reduces the components used.

2. THEORETICAL ANALYSIS

We have analyzed a general buck converter circuit with the following assumptions.

- Ideal switching devices
- No filter capacitor ESR.
- Linear magnetic circuit.

A basic Buck DC-DC converter is shown in Figure1.

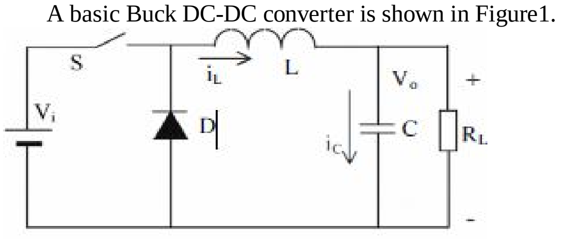


Figure 1. A typical buck DC-DC converter[3]

If the buck converter operates in Continuous Conduction Mode (CCM), the relationship between the input voltage (Vi) and the output voltage(V_o) is:

$$D = V_O / V_i \qquad (1)$$

Where, D is the conducting ratio or duty ratio or duty cycle and $D = \frac{T_{ON}}{T_S}$, T_S is the switching period and T_{ON} is conducting time of the switch.

$$\frac{V_o}{V_i} = \frac{T_{ON}}{T_S} = D \qquad (2)$$

Since, the duty cycle can vary between 0% and 100%, voltage Vo can vary between 0 and Vi. A low duty cycle corresponds to a low output voltage, because the voltage at the buck converter output is zero most of the time. Buck converters implemented with the electronic switch at two different locations relative to the power supply and the load. When the electronic switch is placed on the high voltage side of the power supply, the configuration is called as high side switching as shown in figure 2. Conversely, when the electronic switch is placed on the low voltage side of the power supply, the configuration is called as low side switching as shown in figure 3. Both configurations produce the same output voltage and same current in the load, the low side switching configuration is often preferred instead high side switching configuration because it is easier to implement and requires fewer components. In a buck converter with a load current step, the output capacitor supplies or sinks the immediate difference in current while the inductor current is ramped up or down to match the new load current. A small inductor allows ramping the current quickly to minimize the output capacitor requirement. However, small inductor values also lead to large ripple current requiring a large output capacitor [4].However, the full ripple current flows through the inductor itself, resulting in higher losses and higher peak current requirements for the phase switches.

3. CIRCUITS USED IN LVDAC - EMS

The buck converter circuit with a resistive load and a filtering inductor as shown in figure:

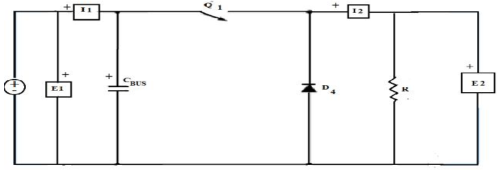


Figure 2. Buck Converter circuit with a resistive load at high side switching in LVDAC-EMS.

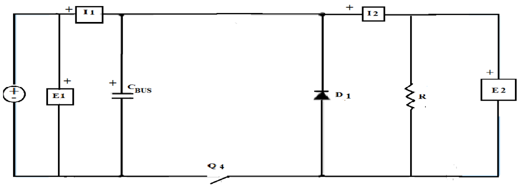


Figure 3. Buck Converter circuit with a resistive load at low side switching in LVDAC-EMS.

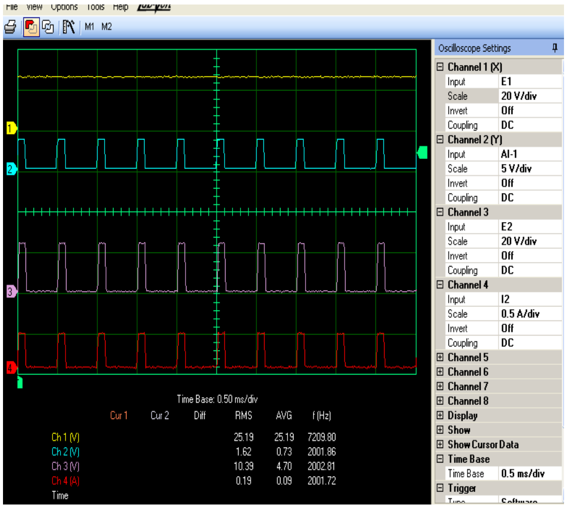
The input voltage in LVDAC-EMS represented by E and the output represented by E2 at a duty cycle of 0.5 or 50% the switching frequency is fixed 2000Hz and the load resistance R. The electronic switch is represented by Q and diode by D. The buck converter circuit with resistive load and for both configurations low side switching and high side switching as shown in Figure 2 and 3.

4. EXPERIMENTAL RESULTS

Theoretical analysis of buck converter presented so far has been verified experimentally using LVDAC-EMS. The experimental setup is as shown in figure 4.The specification of the buck converter is as follows: Input voltage = 25 V, Output voltage = 12.5 V, Duty ratio D = 0.5 from equation 1,Switching frequency(f) = 2000 Hz, Load resistance (R) = 57 ohm,100 ohm,150 ohm.

We have analysed the buck converter circuit experimentally for different values of duty cycle D varying from 0.2 or 20% to 0.8 or 80% as the D value cannot exceed 1, in LVDAC-EMS.The range of switching frequency in LVDAC EMS is from 400 Hz to 20,000Hz.Here, the fixed value of switching frequency of 2000Hz is taken. The output voltage and output current waveforms of low side switching configuration of buck converter for different values of duty cycle as shown in figures 5 to 11.The output voltage and output current waveforms for high side switching configuration are same. The measured values of efficiency at resistive load 57 ohm and output power for different values of resistive load ; 57 ohm, 100 ohm and 150 ohm and power losses for high side switching configuration and low side switching configuration of buck converter are shown in table I,table II and table III respectively. These measured values are plotted with respect to duty cycle as shown in figure 12, 13 and 14 respectively. It shows that higher the duty cyle for same load, higher the efficiency of buck converter. And also larger the value of resistive load at fixed switching frequency, the output power decreases. The low side switching configuration of buck converter have low power dissipation as compared to high side switching configuration of buck converter.

Figure 4: Experimental setup of buck converter.

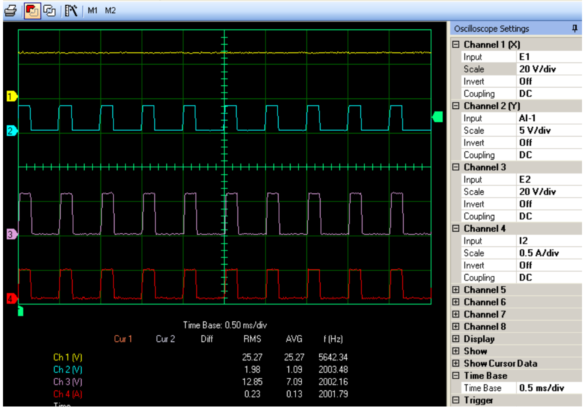


Channel 1 (X)
Input E1
Scale 20 V/div
Invert Off
Coupling DC
Channel 2 (Y)
Input AI-1
Scale 5 V/div
Invert Off
Coupling DC
Channel 3
Input E2
Scale 20 V/div
Invert Off
Coupling DC
Channel 4
Input I2
Scale 0.5 A/div
Invert Off
Coupling DC
Channel 5
Channel 6
Channel 7
Channel 8
Display
Show
Show Cursor Data
Time Base
Time Base 0.5 ms/div
Trigger

```
                 Time Base: 0.50 ms/div
         Cur 1   Cur 2   Diff    RMS     AVG     f (Hz)

Ch 1 (V)                         25.19   25.19   7209.80
Ch 2 (V)                         1.62    0.73    2001.86
Ch 3 (V)                         10.39   4.70    2002.81
Ch 4 (A)                         0.19    0.09    2001.72
Time
```

Figure 5. Waveform of output voltage and output current for low side switching configuration of buck converter at 20% duty cycle with fixed switching frequency 2000Hz.



Channel 1 (X)
Input E1
Scale 20 V/div
Invert Off
Coupling DC
Channel 2 (Y)
Input AI-1
Scale 5 V/div
Invert Off
Coupling DC
Channel 3
Input E2
Scale 20 V/div
Invert Off
Coupling DC
Channel 4
Input I2
Scale 0.5 A/div
Invert Off
Coupling DC
Channel 5
Channel 6
Channel 7
Channel 8
Display
Show
Show Cursor Data
Time Base
Time Base 0.5 ms/div
Trigger

```
                 Time Base: 0.50 ms/div
         Cur 1   Cur 2   Diff    RMS     AVG     f (Hz)

Ch 1 (V)                         25.27   25.27   5642.34
Ch 2 (V)                         1.98    1.09    2003.48
Ch 3 (V)                         12.85   7.09    2002.16
Ch 4 (A)                         0.23    0.13    2001.79
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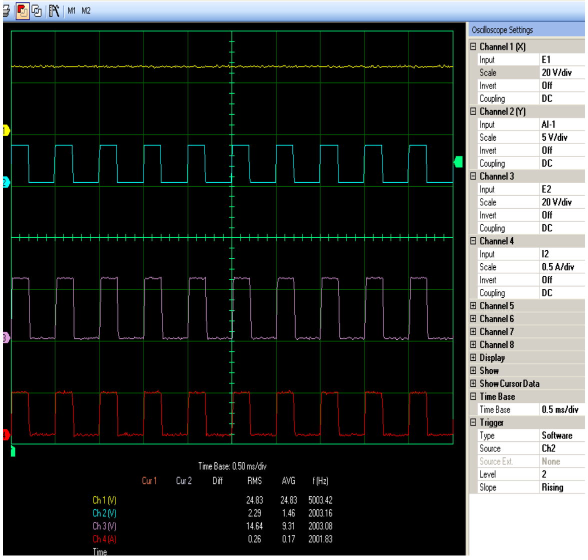
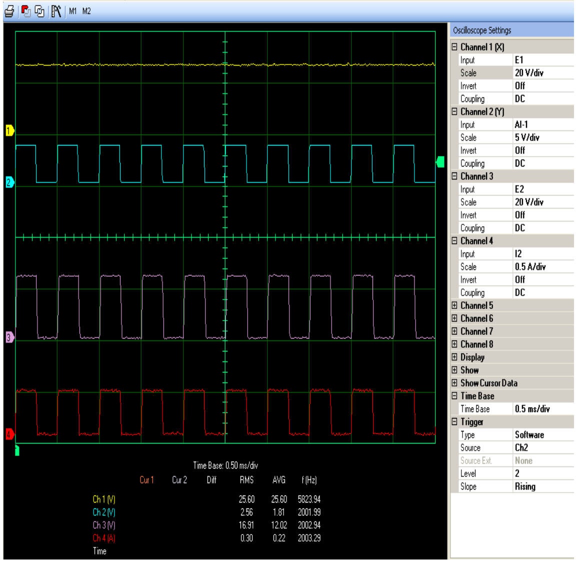
Figure 6. Waveform of output voltage and output current for low side switching configuration of buck converter at 30% duty cycle with fixed switching frequency 2000Hz.



```
Channel 1 (X)
  Input      E1
  Scale      20 V/div
  Invert     Off
  Coupling   DC
Channel 2 (Y)
  Input      AI-1
  Scale      5 V/div
  Invert     Off
  Coupling   DC
Channel 3
  Input      E2
  Scale      20 V/div
  Invert     Off
  Coupling   DC
Channel 4
  Input      I2
  Scale      0.5 A/div
  Invert     Off
  Coupling   DC
Channel 5
Channel 6
Channel 7
Channel 8
Display
Show
Show Cursor Data
Time Base
  Time Base  0.5 ms/div
Trigger
  Type       Software
  Source     Ch2
  Source Ext. None
  Level      2
  Slope      Rising

                 Time Base: 0.50 ms/div
          Cur 1   Cur 2   Diff    RMS     AVG     f (Hz)
Ch 1 (V)                          24.83   24.83   5003.42
Ch 2 (V)                          2.29    1.46    2003.16
Ch 3 (V)                          14.64   9.31    2003.08
Ch 4 (A)                          0.26    0.17    2001.83
Time
```

Figure 7. Waveform of output voltage and output current for low side switching configuration of buck converter at 40% duty cycle with fixed switching frequency 2000Hz.



```
Channel 1 (X)
  Input      E1
  Scale      20 V/div
  Invert     Off
  Coupling   DC
Channel 2 (Y)
  Input      AI-1
  Scale      5 V/div
  Invert     Off
  Coupling   DC
Channel 3
  Input      E2
  Scale      20 V/div
  Invert     Off
  Coupling   DC
Channel 4
  Input      I2
  Scale      0.5 A/div
  Invert     Off
  Coupling   DC
Channel 5
Channel 6
Channel 7
Channel 8
Display
Show
Show Cursor Data
Time Base
  Time Base  0.5 ms/div
Trigger
  Type       Software
  Source     Ch2
  Source Ext. None
  Level      2
  Slope      Rising

                 Time Base: 0.50 ms/div
          Cur 1   Cur 2   Diff    RMS     AVG     f (Hz)
Ch 1 (V)                          25.60   25.60   5823.94
Ch 2 (V)                          2.56    1.81    2001.99
Ch 3 (V)                          16.91   12.02   2002.94
Ch 4 (A)                          0.30    0.22    2003.29
Time
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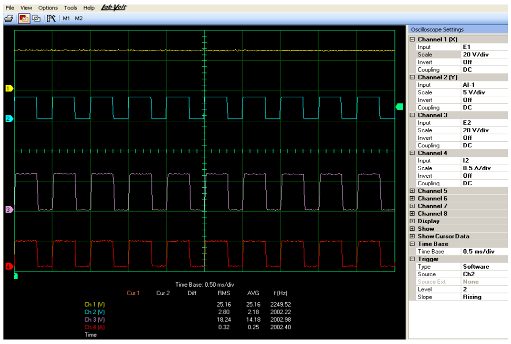
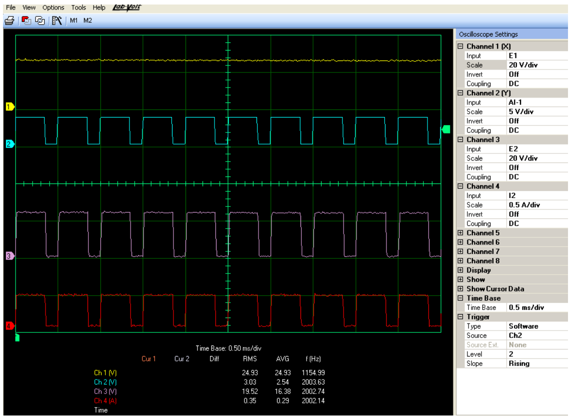
Figure 8. Waveform of output voltage and output current for low side switching configuration of buck converter at 50% duty cycle with fixed switching frequency 2000Hz.



```
Channel 1 (X)
  Input      E1
  Scale      20 V/div
  Invert     Off
  Coupling   DC
Channel 2 (Y)
  Input      AI-1
  Scale      5 V/div
  Invert     Off
  Coupling   DC
Channel 3
  Input      E2
  Scale      20 V/div
  Invert     Off
  Coupling   DC
Channel 4
  Input      I2
  Scale      0.5 A/div
  Invert     Off
  Coupling   DC
Channel 5
Channel 6
Channel 7
Channel 8
Display
Show
Show Cursor Data
Time Base
  Time Base  0.5 ms/div
Trigger
  Type       Software
  Source     Ch2
  Source Ext. None
  Level      2
  Slope      Rising

                 Time Base: 0.50 ms/div
          Cur 1   Cur 2   Diff    RMS     AVG     f (Hz)
Ch 1 (V)                          25.16   25.16   2249.52
Ch 2 (V)                          2.80    2.18    2002.22
Ch 3 (V)                          18.24   14.18   2002.98
Ch 4 (A)                          0.32    0.25    2002.40
Time
```

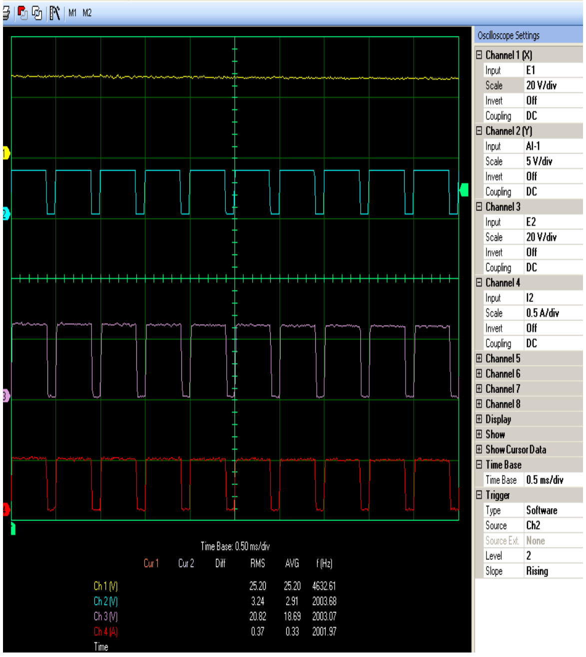
Figure 9. Waveform of output voltage and output current for low side switching configuration of buck converter at 60% duty cycle with fixed switching frequency 2000Hz.



```
Channel 1 (X)
  Input      E1
  Scale      20 V/div
  Invert     Off
  Coupling   DC
Channel 2 (Y)
  Input      AI-1
  Scale      5 V/div
  Invert     Off
  Coupling   DC
Channel 3
  Input      E2
  Scale      20 V/div
  Invert     Off
  Coupling   DC
Channel 4
  Input      I2
  Scale      0.5 A/div
  Invert     Off
  Coupling   DC
Channel 5
Channel 6
Channel 7
Channel 8
Display
Show
Show Cursor Data
Time Base
  Time Base  0.5 ms/div
Trigger
  Type       Software
  Source     Ch2
  Source Ext. None
  Level      2
  Slope      Rising

                 Time Base: 0.50 ms/div
          Cur 1   Cur 2   Diff    RMS     AVG     f (Hz)
Ch 1 (V)                          24.93   24.93   1154.99
Ch 2 (V)                          3.03    2.54    2003.63
Ch 3 (V)                          19.52   16.38   2002.74
Ch 4 (A)                          0.35    0.29    2002.14
Time
```

Figure 10. Waveform of output voltage and output current for low side switching configuration of buck converter at 70% duty cycle with fixed switching frequency 2000Hz.



```
Channel 1 (X)
  Input      E1
  Scale      20 V/div
  Invert     Off
  Coupling   DC
Channel 2 (Y)
  Input      AI-1
  Scale      5 V/div
  Invert     Off
  Coupling   DC
Channel 3
  Input      E2
  Scale      20 V/div
  Invert     Off
  Coupling   DC
Channel 4
  Input      I2
  Scale      0.5 A/div
  Invert     Off
  Coupling   DC
Channel 5
Channel 6
Channel 7
Channel 8
Display
Show
Show Cursor Data
Time Base
  Time Base  0.5 ms/div
Trigger
  Type       Software
  Source     Ch2
  Source Ext. None
  Level      2
  Slope      Rising

                 Time Base: 0.50 ms/div
          Cur 1   Cur 2   Diff    RMS     AVG     f (Hz)
Ch 1 (V)                          25.20   25.20   4632.61
Ch 2 (V)                          3.24    2.91    2003.68
Ch 3 (V)                          20.82   18.69   2003.07
Ch 4 (A)                          0.37    0.33    2001.97
Time
```

Figure 11. Waveform of output voltage and output current for low side switching configuration of buck converter at 80% duty cycle with fixed switching frequency 2000Hz.

Table I. Duty cycle versus efficiency at load resistance of 57 ohm.

Duty Cycle **Duty Cycle**	**Efficiency % at R = 57 ohm** **Efficiency % at R = 57 ohm**
0.2	91.17
0.4	92.03
0.6	93.57
0.8	97.82

Table II. Duty cycle versus output power at different load resistances.

a. Power loss1 At high side switching.
b. Power loss2 At low side switching

Duty Cycle	Power Loss1(W)	Power Loss2(W)
0.2	0.248	0.99
0.3	0.23	0.184
0.4	0.129	0.089
0.5	0.254	0.234
0.6	0.491	0.44
0.7	0.369	0.338
0.8	0.522	0.479

Table III: Duty cycle versus power losses at load resistance of 57 ohm.

Duty Cycl	R = 57 Ohm	R = 100 Ohm	R = 150 Ohm
0.2	1.8612	1.1649	0.7357
0.4	3.7856	2.277	1.6863
0.6	5.7792	3.5226	2.418
0.8	8.0902	4.6596	3.231

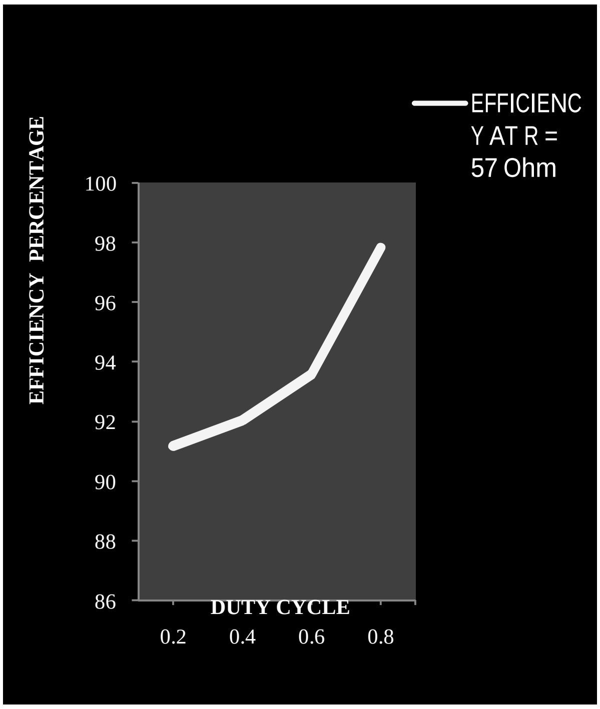


Figure 12. Duty Cycle versus Efficiency at Load Resistance of 57 Ohm.

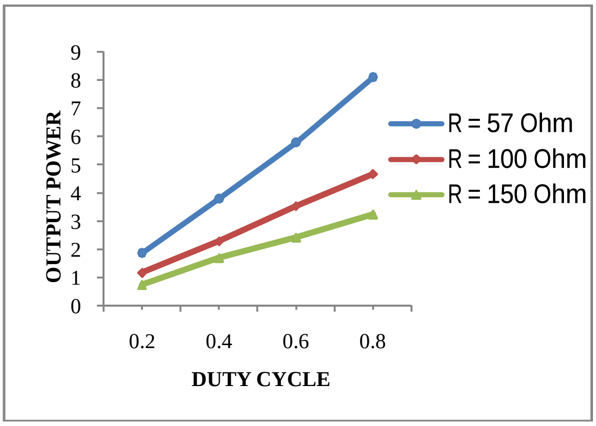


Figure 13. Duty Cycle versus Output Power at different Load Resistances.

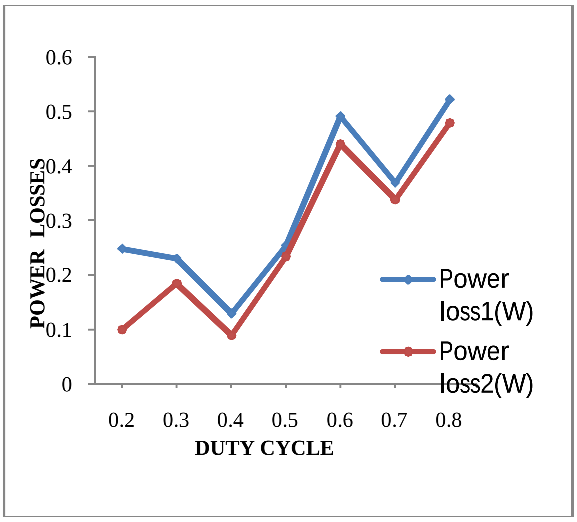


Figure 14. Duty Cycle versus Power Losses at Load Resistance of 57 Ohm.

c. Power loss1 at high side switching.
d. Power loss2 at low side switching.

5. CONCLUSION

The proposed technique has been applied to the design of low side and high side switching configurations of buck converter operating at 12.5 V output from a 25 V input (Figure.1).The switching frequency is fixed 2000Hz.The duty cycle is varied from 20% to 80 %. The buck converter power stage utilizes a 57 ohm, 100 ohm and 150 ohm load resistors. Tests on the system were conducted using LVDAC-EMS software. Tests described here were performed using a resistive load. The voltage across the resistor is used as the metric for output voltage. By experimental results, it is concluded that the output power decreases as the load increases. Power losses are less using low side switching configuration instead of high side switching configuration. The efficiency of buck converter increases, as the duty cycle increases. Experimental results have been provided to verify the analysis presented.

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