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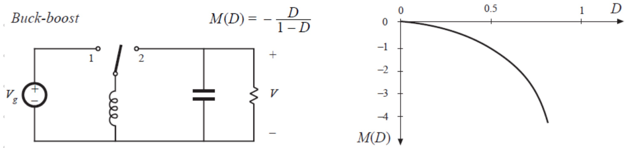
29450

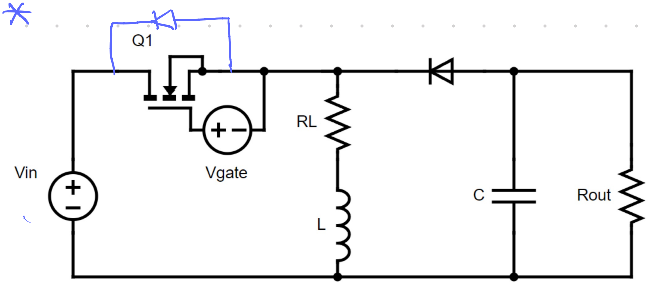
- ME408 Project Part 2 -



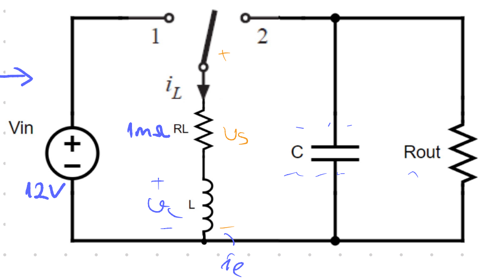
* Duty cycle $(D) = \dfrac{t_{on}}{t_{on}+t_{off}} = \dfrac{t_{on}}{T_s}$

* $V_o = M(D)\cdot V_{in} \Rightarrow V_o = \dfrac{-D}{1-D} V_{in}$

*

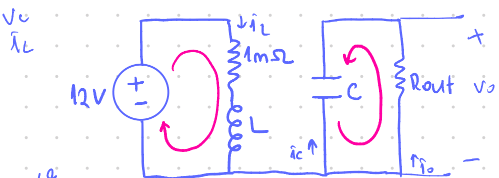


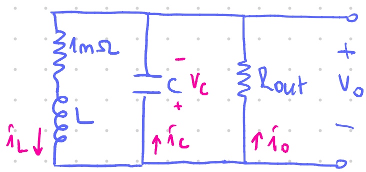
Non-idal Buck-Boost Converter



Switch at position 1:

Switch at position 2:





$$C\frac{dV_o}{dt} + \frac{V_o}{R_{out}} = i_L$$

$\Rightarrow L\dfrac{di_L}{dt} + R_L i_L = V_{in}$

↳ $v_L = V_{in} - I \cdot R_L$

$\Rightarrow i_c = -i_o \Rightarrow C\cdot\dfrac{dV_c}{dt} = \dfrac{V_o}{R_{out}}$ $V_o \approx V$

↳ $i_c = \dfrac{+V}{R_{out}}$

$\Rightarrow L\dfrac{di_L}{dt} + R_L i_L = V_o$

$v_L = v_o - R_L \cdot i_L \Rightarrow v_L = V - R_L \cdot I$

$\Rightarrow i_c = i_L - i_o \Rightarrow i_c = i_L + \dfrac{v(t)}{R_{out}} \rightarrow$ $v(t)$: small ripple $\approx V$

↳ $i_c = I + \dfrac{V}{R_{out}}$

↳ $C\cdot\dfrac{dV_c}{dt} = I + \dfrac{V}{R_{out}}$

Lap. $\begin{cases} \dfrac{1}{C}\int (i_L - i_o)\,dt = -V_o \\ \dfrac{1}{CS} I_L(s) + \dfrac{1}{CS\cdot R_{out}} V_o(s) = -V_o(s) \end{cases}$

$V_s = R_L i_L + L\dfrac{d}{dt} i_L \overset{Lap.}{\Rightarrow} V_s(s) = LS\,I_L(s) + R_L I_L(s)$

↳ $V_s(s) = I_L(LS + R_L) \Rightarrow I_L(s) = \dfrac{V_s(s)}{(LS+R_L)}$

$$\frac{1}{CS}\cdot\frac{V_s(s)}{(LS+R_L)} = -V_o(s)\left(\frac{CSR_{out}+1}{CSR_{out}}\right) \rightarrow \frac{V_o}{V_s} = -\frac{\cancel{CS}R_{out}}{\cancel{CS}(LS+R_L)(CSR_{out}+1)} \Rightarrow H_p(s) = \frac{-R_{out}}{s^2(LCR_{out}) + s(L + CR_LR_{out}) + R_L}$$

* You pick the switching frequency (f>1kHz). You can add additional circuit elements to the above design (some will be necessary).

$*$ Switching frequency:

$f_s > 1\text{kHz} \rightarrow T_s < 0.001\ s$

I first tried $f_s = 20\text{kHz} \rightarrow T_s = \underbrace{0.05\text{ms}}_{50e^{-6}\ \text{sec}}$

↳ $f_{cutoff} = \frac{20000}{100} = 200\text{Hz}$

(2 decades away from f_s)

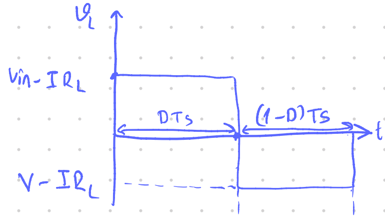
@ Cutoff frequency $H_f(s) = \frac{1}{\sqrt{2}}$

↳ $f_c = 200\text{Hz} \Rightarrow \omega_c = 2\pi 200 = 400\pi\ s$

$s = j\omega \Rightarrow s = 400\pi j$

$$H_f(s) = \left| \frac{-R_{out}}{s^2(LCR_{out}) + s(L + CR_L R_{out}) + R_L} \right|_{s=j\omega_c} = \frac{1}{\sqrt{2}}$$

$$\omega_c^2 (LCR_{out}) - j\omega_c (L + CR_L R_{out}) - R_L = \sqrt{2} R_{out}$$



$$(V_{in} - IR_L)D\cancel{T_s} + (1-D)\cancel{T_s}(V - IR_L) = 0$$

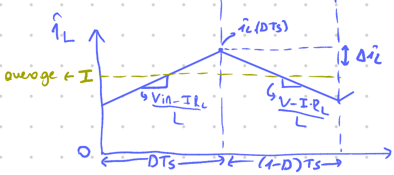
$$\hookrightarrow V_{in} \cdot D - I\cancel{R_L \cdot D} + V - IR_L - V \cdot D + I\cancel{R_L \cdot D} = 0$$

$$V_{in} \cdot D = -V + IR_L + VD$$

$$V_{in} = \frac{-V(1-D)}{D} + \frac{IR_L}{D} \Rightarrow IR_L = (V_{in} \cdot D) + V(1-D)$$

$$\hookrightarrow V = \frac{IR_L - V_{in} \cdot D}{(1-D)}$$

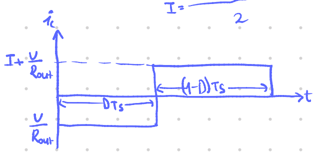
$$\rightarrow v_L(t) = L \cdot \frac{di_L}{dt}$$



$$I = \frac{i_L \cdot DT_s + \cancel{i_L(0)}^{\,0}}{2}$$

(switch @ 1) $\rightarrow \frac{2\Delta i_L}{\Delta t \rightarrow DT_s} = \frac{V_{in} - IR_L}{L} \Rightarrow 2\Delta i_L = \frac{(V_{in} - IR_L) \cdot DT_s}{L} \Rightarrow L = \frac{(V_{in} - IR_L)DT_s}{2\Delta i_L}$

(switch @ 2) $\rightarrow \frac{2\Delta i_L}{\Delta t \rightarrow (1-D)T_s} = \frac{V - I \cdot R_L}{L} \Rightarrow 2\Delta i_L = \frac{(V - IR_L)(1-D)T_s}{L}$



$$\hookrightarrow \left(\frac{V}{R_{out}}\right)D\cancel{T_s} + \left(I + \frac{V}{R_{out}}\right)(1-D)\cancel{T_s} = 0$$

$$\rightarrow \frac{V \cdot \cancel{D}}{\cancel{R_{out}}} + I + \frac{V}{R_{out}} - ID - \frac{V\cancel{D}}{\cancel{R_{out}}} = 0 \qquad V = \frac{IR_L - V_{in} \cdot D}{(1-D)}$$

$$\rightarrow I(1-D) = \frac{-V}{R_{out}} \quad \rightarrow \quad I = \frac{-V}{(1-D) \cdot R_{out}} \rightarrow I = \frac{V_{in} \cdot D - I \cdot R_L}{R_{out} \cdot (1-D)^2}$$

$$\rightarrow R_{out} \cdot (1-D)^2 \cdot I + I \cdot R_L = V_{in} \cdot D$$

$$\hookrightarrow I(R_{out} \cdot (1-D)^2 + R_L) = V_{in} \cdot D$$

$$\hookrightarrow I = \frac{V_{in} \cdot D}{(R_{out} \cdot (1-D)^2 + R_L)}$$

used in motor

used in motor

$$\hookrightarrow \quad C \cdot \frac{dv_C}{dt} = i_C = I + \frac{V}{R_{out}} \quad (\text{@ switch } 1)$$

used in motor

$$C \cdot \frac{dv_C}{dt} = \frac{V_{in} D}{(R_{out} \cdot (1-D)^2 + R_L)} + \frac{IR_L - V_{in} D}{(1-D) \cdot R_{out}} = \frac{V_{in} D}{(R_{out}(1-D)^2 + R_L)} + \frac{\frac{V_{in} \cdot D \cdot R_L}{(R_{out}(1-D)^2 + R_L)} - V_{in} \cdot D}{(1-D) \cdot R_{out}}$$

$$= \frac{V_{in} \cdot D}{(R_{out}(1-D)^2 + R_L)} + \frac{V_{in} \cdot D \cdot R_L}{((R_{out}(1-D)^2 + R_L)(1-D) \cdot R_{out})} - \frac{V_{in} \cdot D}{(1-D) \cdot R_{out}}.$$

$$= \frac{V_{in} D(1-D) \cdot R_{out} + V_{in} D \cdot R_L + V_{in} D(R_{out}(1-D)^2 + R_L)}{(R_{out}(1-D)^2 + R_L)(1-D) R_{out}} = \frac{V_{in} \cdot R_{out} \cdot D(1-D)(2-D) + 2V_{in} D R_L}{(R_{out}(1-D)^2 + R_L)(1-D) R_{out}}$$

$$\hookrightarrow \Delta v_C = \left[\frac{V_{in} \cdot R_{out} \cdot D(1-D)(2-D) + 2V_{in} D R_L}{(R_{out}(1-D)^2 + R_L)(1-D) R_{out}}\right] \frac{DT_s}{C} \Rightarrow C = \left[\frac{V_{in} \cdot R_{out} \cdot D(1-D)(2-D) + 2V_{in} D R_L}{(R_{out}(1-D)^2 + R_L)(1-D) R_{out}}\right] \frac{D \cdot T_s}{\Delta v_C}$$

Matlab :

```
clc
clear all;

Vin = 12;
D = 0.7;
Ts = 50e-6;
Rout = 100;
Rl = 1e-3;

current_ripple_L = 0.05;
voltage_ripple_C = 0.2;

I = (Vin * D)/(Rout*(1-D)^2 + Rl);

L = (Vin*D - I*Rl) * D*Ts / (current_ripple_L)
C = (((Vin*D)/(Rout * (1-D)^2 +Rl)) + ((I*Rl - Vin*D)/((1-D)*Rout))) * (D*Ts/voltage_ripple_C)
```

Command Window

```
L =

    0.0059

C =

   1.1432e-04
```

0.0059 = 5.9 mH

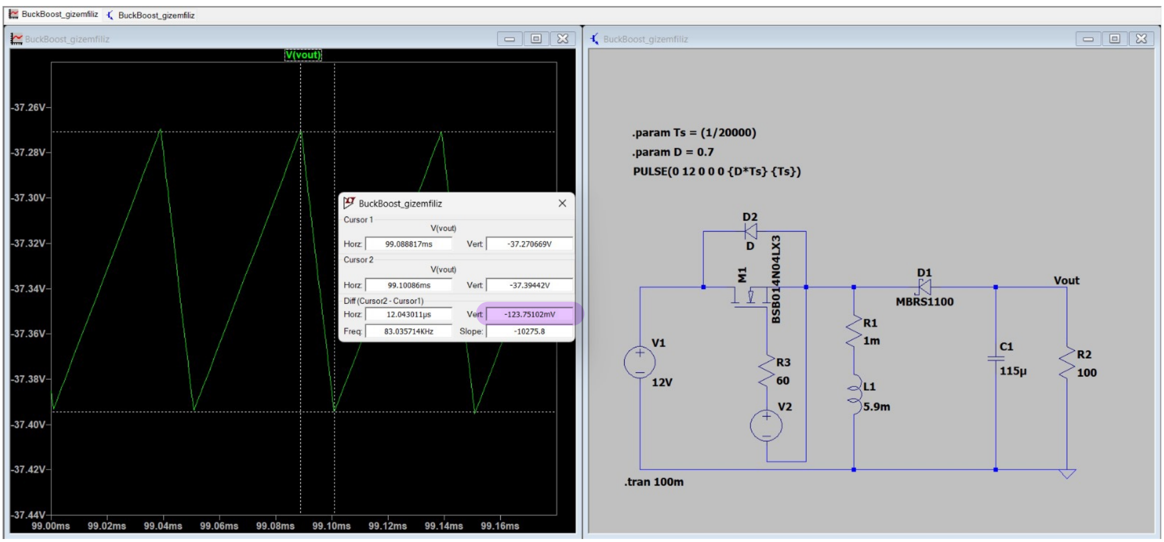
1.1432e-04 = 114.32 μF

* We would like stable results especially around the 0.3<D<0.7 band (where D is the duty cycle). That's the main operation zone.

Current ripple is important for the motor and therefore the permissible inductor current ripple is 0.05A (peak to peak). < 50 mA

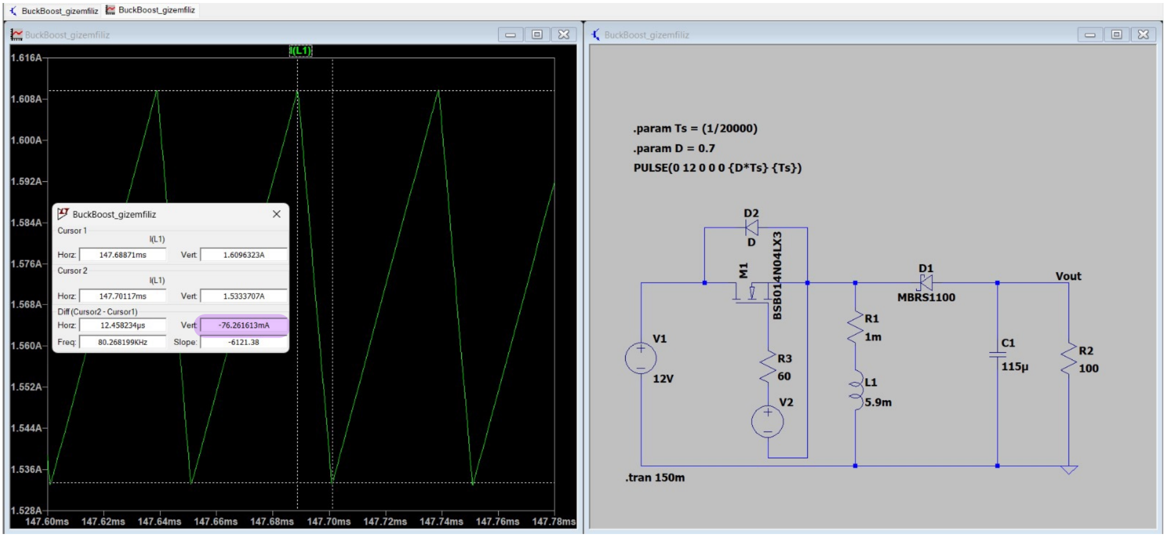
Permissible capacitor voltage is 0.2V (peak to peak). < 200 mV

* D = 0,7 :



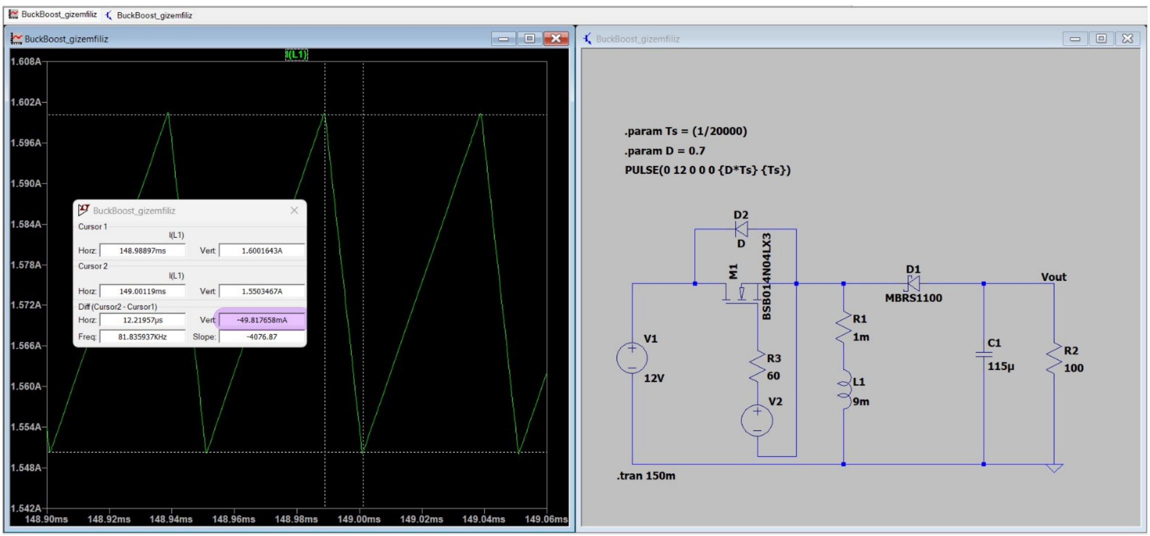
↳ i_L current ripple is inside the boundary.

However;



V_c votage ripple exceed the boundary 76.26mA ~~<~~ 50 mA

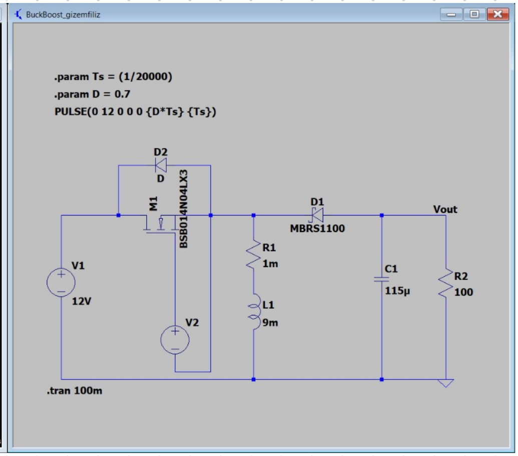
↳ So, I increased L1 inductance to 9mH.

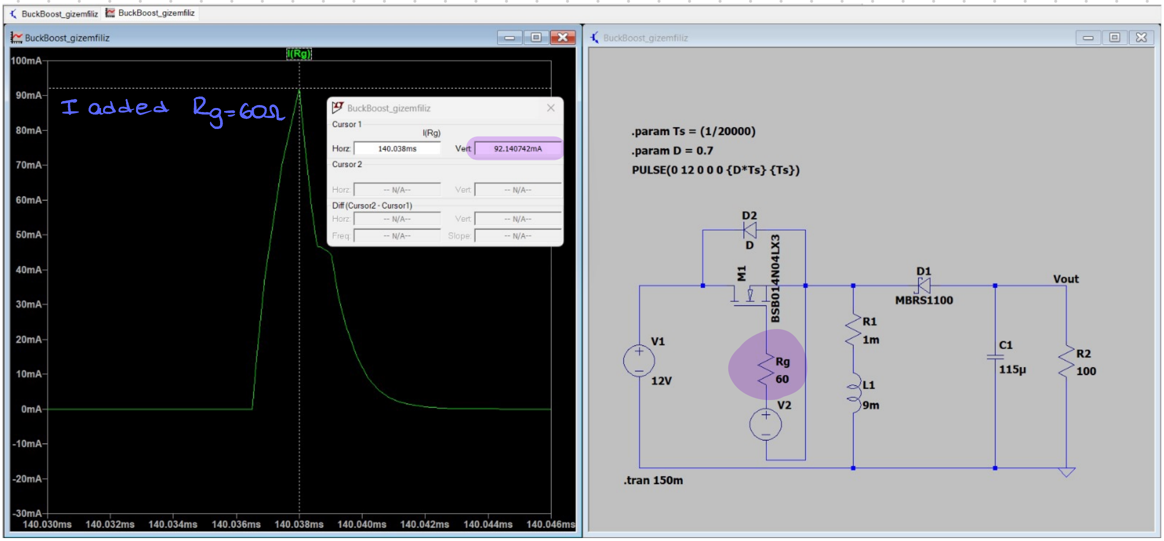


↳ i_L current ripple didn't change. ≅ 123 mV < 200 mV (inside the boundary.)

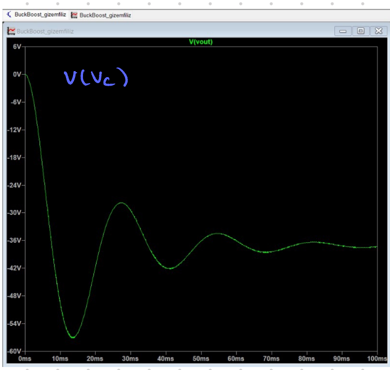
↳ V_c voltage ripple decreased to 49.81 mA < 50mA (" " ")

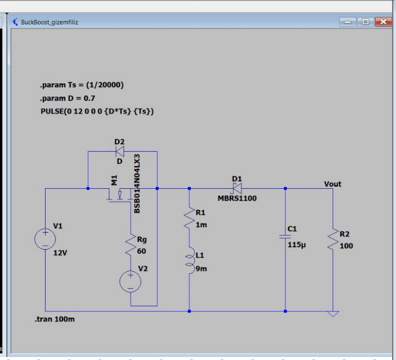
Peak value for i_g should not surpass 100mA. What can you change to reduce this current? Make the necessary changes. What is the tradeoff?

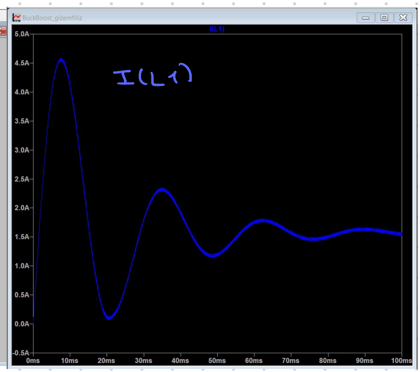




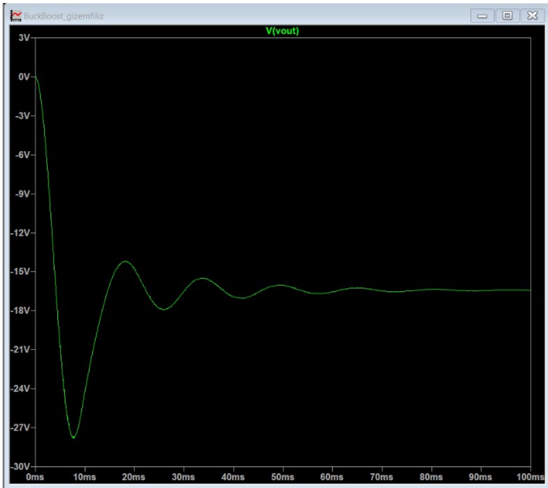
gate current i_g = 92,140 mA (100 mA (inside the boundory)

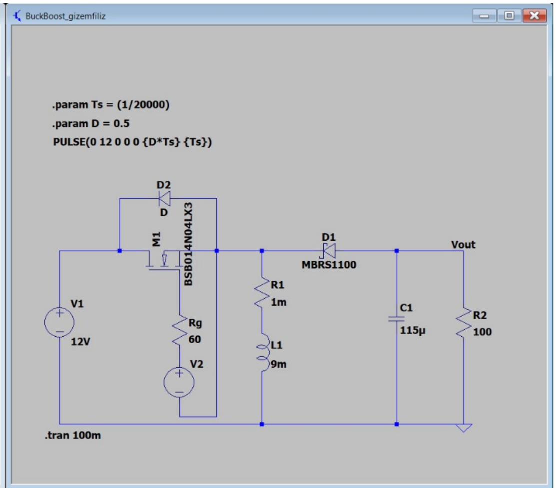


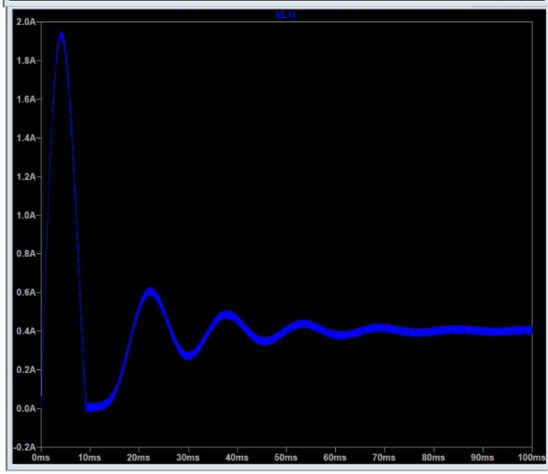


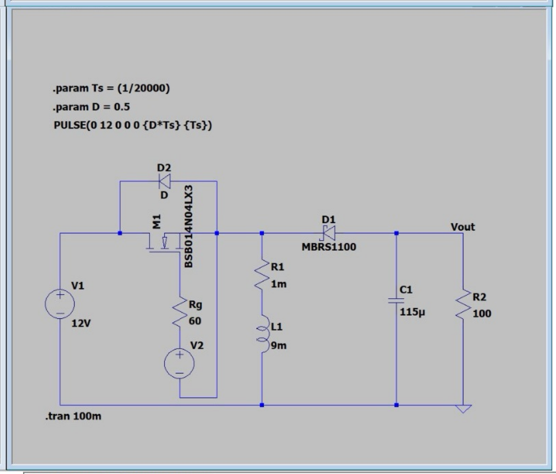


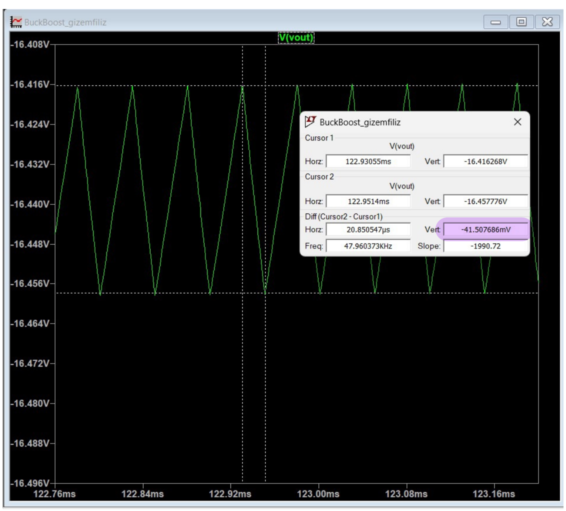
* D= 0,5

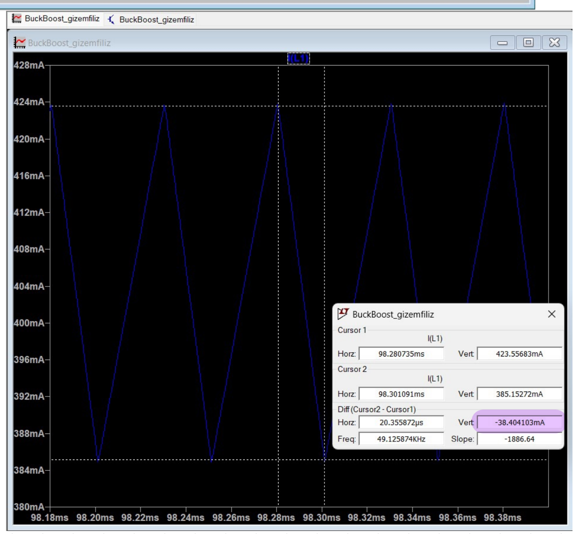

BuckBoost_gizemfiliz
V(vout)
3V
0V
-3V
-6V
-9V
-12V
-15V
-18V
-21V
-24V
-27V
-30V
0ms
10ms
20ms
30ms
40ms
50ms
60ms
70ms
80ms
90ms
100ms


BuckBoost_gizemfiliz
.param Ts = (1/20000)
.param D = 0.5
PULSE(0 12 0 0 0 {D*Ts} {Ts})
D2
D
M1
BSB014N04LX3
D1
MBRS1100
Vout
V1
12V
R1
1m
L1
9m
Rg
60
V2
C1
115µ
R2
100
.tran 100m

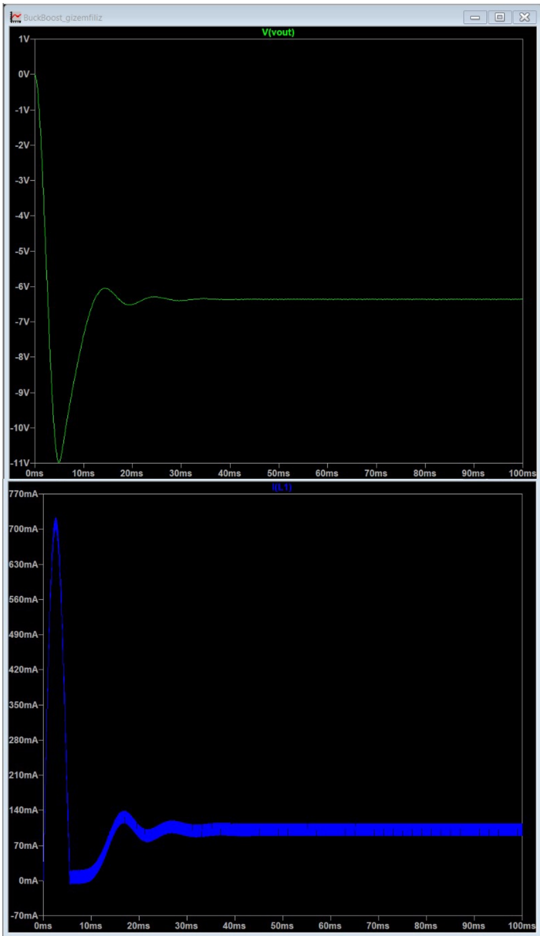

I(L1)
2.0A
1.8A
1.6A
1.4A
1.2A
1.0A
0.8A
0.6A
0.4A
0.2A
0.0A
-0.2A
0ms
10ms
20ms
30ms
40ms
50ms
60ms
70ms
80ms
90ms
100ms

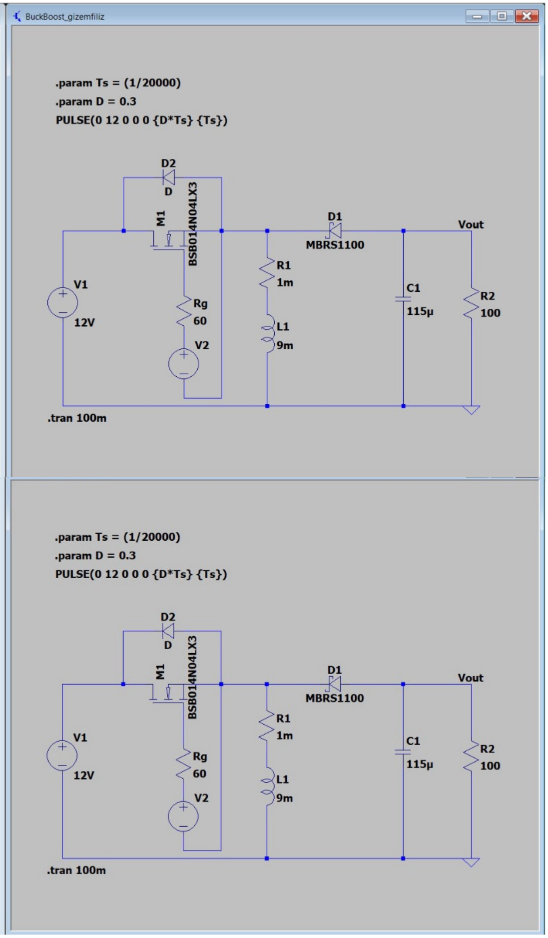

.param Ts = (1/20000)
.param D = 0.5
PULSE(0 12 0 0 0 {D*Ts} {Ts})
D2
D
M1
BSB014N04LX3
D1
MBRS1100
Vout
V1
12V
R1
1m
L1
9m
Rg
60
V2
C1
115µ
R2
100
.tran 100m

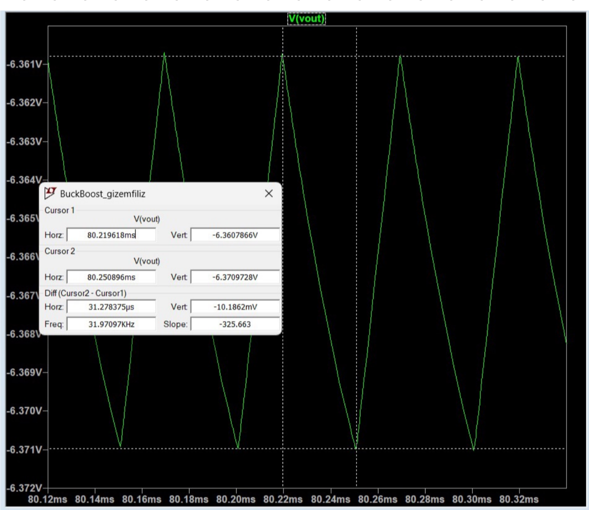

BuckBoost_gizemfiliz
V(vout)
-16.408V
-16.416V
-16.424V
-16.432V
-16.440V
-16.448V
-16.456V
-16.464V
-16.472V
-16.480V
-16.488V
-16.496V
122.76ms
122.84ms
122.92ms
123.00ms
123.08ms
123.16ms
BuckBoost_gizemfiliz
Cursor 1
V(vout)
Horz: 122.93055ms
Vert: -16.416268V
Cursor 2
V(vout)
Horz: 122.9514ms
Vert: -16.457776V
Diff (Cursor2 - Cursor1)
Horz: 20.850547µs
Vert: -41.507686mV
Freq: 47.960373KHz
Slope: -1990.72

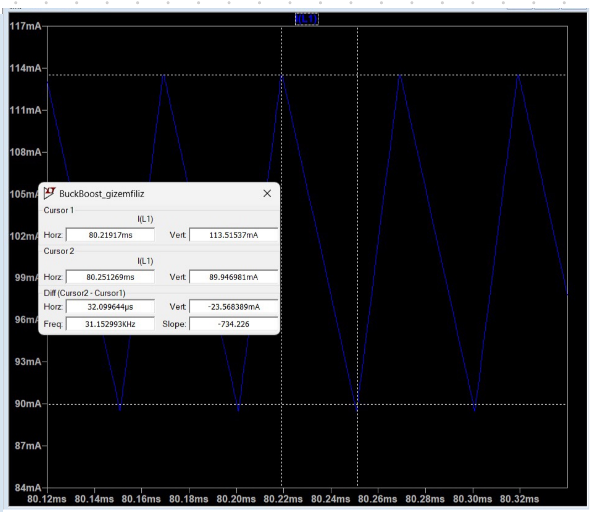

BuckBoost_gizemfiliz
BuckBoost_gizemfiliz
I(L1)
428mA
424mA
420mA
416mA
412mA
408mA
404mA
400mA
396mA
392mA
388mA
384mA
380mA
98.18ms
98.20ms
98.22ms
98.24ms
98.26ms
98.28ms
98.30ms
98.32ms
98.34ms
98.36ms
98.38ms
BuckBoost_gizemfiliz
Cursor 1
I(L1)
Horz: 98.280735ms
Vert: 423.55683mA
Cursor 2
I(L1)
Horz: 98.301091ms
Vert: 385.15272mA
Diff (Cursor2 - Cursor1)
Horz: 20.355872µs
Vert: -38.404103mA
Freq: 49.125874KHz
Slope: -1886.64

D = 0.3


BuckBoost_gizemfiliz
V(vout)
1V
0V
-1V
-2V
-3V
-4V
-5V
-6V
-7V
-8V
-9V
-10V
-11V
0ms 10ms 20ms 30ms 40ms 50ms 60ms 70ms 80ms 90ms 100ms
I(L1)
770mA
700mA
630mA
560mA
490mA
420mA
350mA
280mA
210mA
140mA
70mA
0mA
-70mA
0ms 10ms 20ms 30ms 40ms 50ms 60ms 70ms 80ms 90ms 100ms


BuckBoost_gizemfiliz
.param Ts = (1/20000)
.param D = 0.3
PULSE(0 12 0 0 0 {D*Ts} {Ts})
D2
D
M1
BSB014N04LX3
D1
MBRS1100
Vout
R1
1m
V1
12V
Rg
60
V2
L1
9m
C1
115µ
R2
100
.tran 100m
.param Ts = (1/20000)
.param D = 0.3
PULSE(0 12 0 0 0 {D*Ts} {Ts})
D2
D
M1
BSB014N04LX3
D1
MBRS1100
Vout
R1
1m
V1
12V
Rg
60
V2
L1
9m
C1
115µ
R2
100
.tran 100m


V(vout)
-6.361V
-6.362V
-6.363V
-6.364V
-6.365V
-6.366V
-6.367V
-6.368V
-6.369V
-6.370V
-6.371V
-6.372V
80.12ms 80.14ms 80.16ms 80.18ms 80.20ms 80.22ms 80.24ms 80.26ms 80.28ms 80.30ms 80.32ms
BuckBoost_gizemfiliz
Cursor 1
V(vout)
Horz: 80.219618ms Vert: -6.3607866V
Cursor 2
V(vout)
Horz: 80.250896ms Vert: -6.3709728V
Diff (Cursor2 - Cursor1)
Horz: 31.278375µs Vert: -10.1862mV
Freq: 31.97097KHz Slope: -325.663


I(L1)
117mA
114mA
111mA
108mA
105mA
102mA
99mA
96mA
93mA
90mA
87mA
84mA
80.12ms 80.14ms 80.16ms 80.18ms 80.20ms 80.22ms 80.24ms 80.26ms 80.28ms 80.30ms 80.32ms
BuckBoost_gizemfiliz
Cursor 1
I(L1)
Horz: 80.21917ms Vert: 113.51537mA
Cursor 2
I(L1)
Horz: 80.251269ms Vert: 89.946981mA
Diff (Cursor2 - Cursor1)
Horz: 32.099644µs Vert: -23.568389mA
Freq: 31.152993KHz Slope: -734.226

* ?

@ Cutoff frequency $H_f(s) = \frac{1}{\sqrt{2}}$

↳ $f_c = 200Hz \Rightarrow w_c = 2\pi 200 = 400\pi$ s

$s = jw \Rightarrow s = 400\pi j$

$$H_f(s) = \left| \frac{-R_{out}}{s^2(LCR_{out}) + s(L + CR_L R_{out}) + R_L} \right|_{s=jw_c} = \frac{1}{\sqrt{2}}$$

$$= \left| \frac{-100}{(400j)^2(9\times10^{-3}\times115\times10^{-6}\times100) + (400j)(9\times10^{-3} + 115\times10^{-6}\times10^{-3}\times100) + 10^{-3}} \right| =$$

$$= \left| \frac{-100}{-16,559 + 3,6046j} \right| = \left| \frac{1655,9 + 360,46j}{274,200481 + 12,99314116} \right| = 5,76579 \ ?$$

$(-16,559 - 3,6046j)$

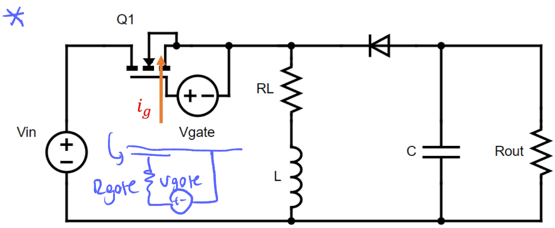
$$\left| \frac{-100}{(-w_c^2 \cdot (1.035\times10^{-4}) + 0.001) + w_c j(1.15\times10^{-5})} \right| = \frac{1}{\sqrt{2}}$$

$(-w_c^2 \cdot (1.035\times10^{-4}) + 0.001) - w_c j(1.15\times10^{-5})$

↳ $$\frac{-100 \cdot \left((-w_c^2 \cdot (1.035\times10^{-4}) + 0.001) - w_c j(1.15\times10^{-5})\right)}{(-w_c^2 \cdot (1.035\times10^{-4}) + 0.001)^2 + (w_c(1.15\times10^{-5}))^2} = \frac{1}{\sqrt{2}}$$

→ Couldn't solve for w_c

*



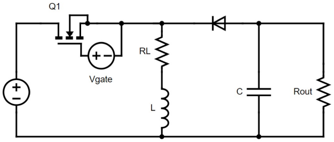
Peak value for i_g should not surpass 100mA. What can you change to reduce this current? Make the necessary changes. What is the tradeoff?

I added $R_{gate} = 60\Omega$ to my circuit in order to decrease the i_g current

↳ $i_{gate} = \frac{V_{gate}}{R_{gate}}$

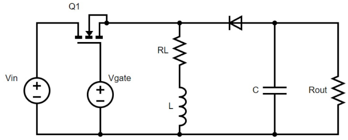
However this caused $R_{gate} \times C_{gate}$ to increase. Thus, τ_{gate} increased. resulting in an increase in the rise and fall times of the MOSFET. So the switching speed of the MOSFET dropped. This also causes power dissipation during each switching event.

Case 1:

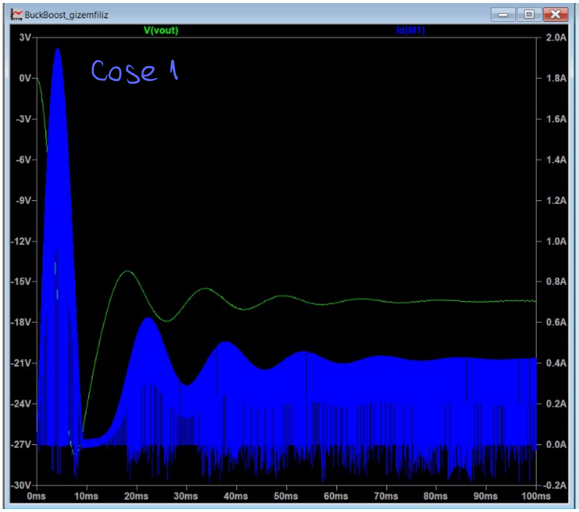


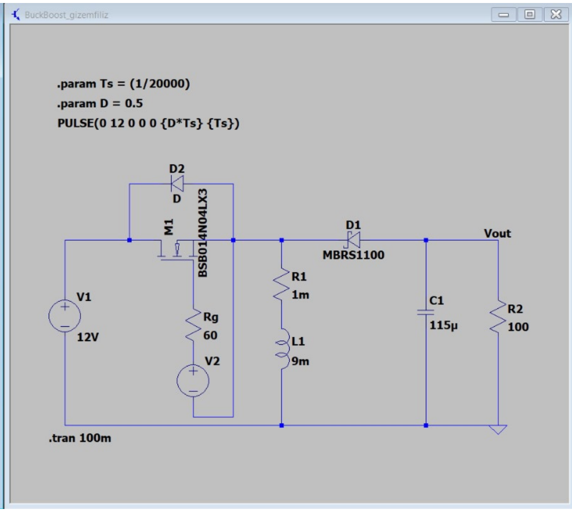
VS

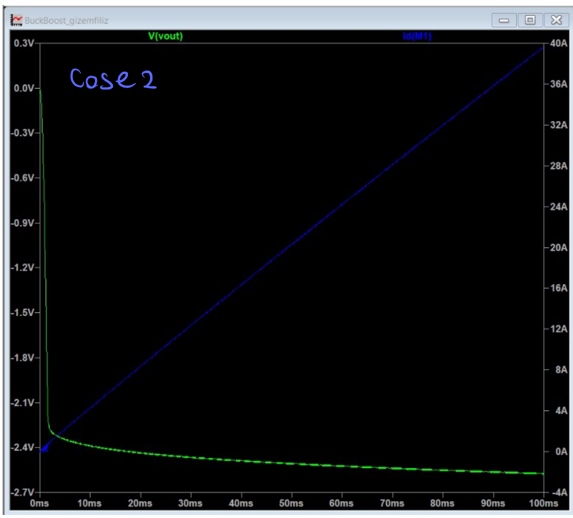
Case 2:

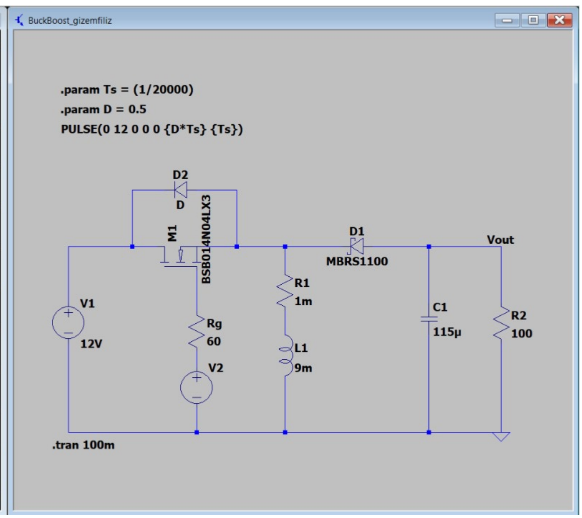


For what reason is the left configuration was chosen for the gate pulse generator? Compare the current through the MOSFET drain source for both configurations. You can also check the same current for your buck converters (or the boost converter on Sucourse) to get a better idea.





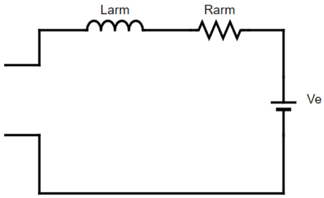




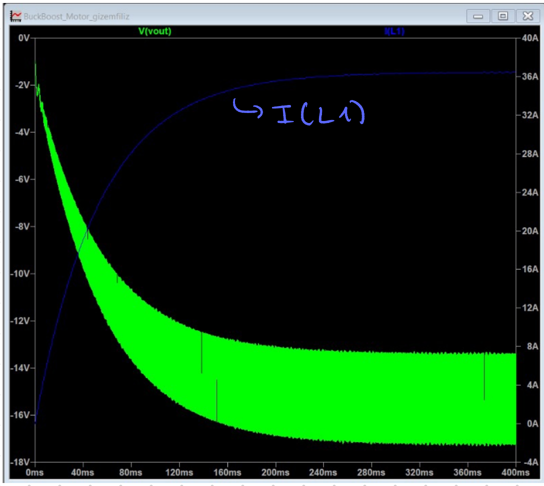
In case 2, we can see that Drain current grows unboundedly, which also results in lower output voltage (overdamped)

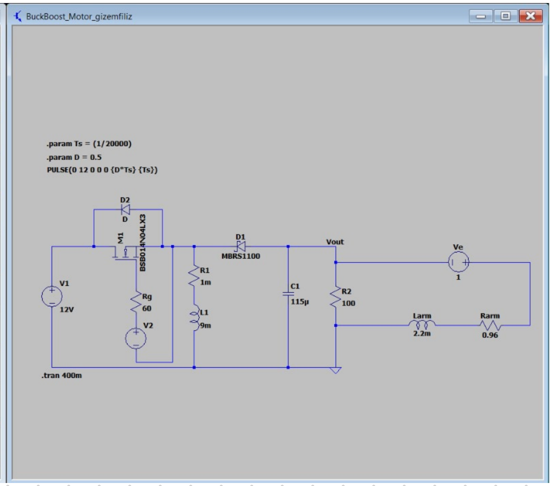
* Motor Armature:

The Dc motor is rated for 12-36Volts.
Larm = 2.2mH   Rarm = 0.96Ω



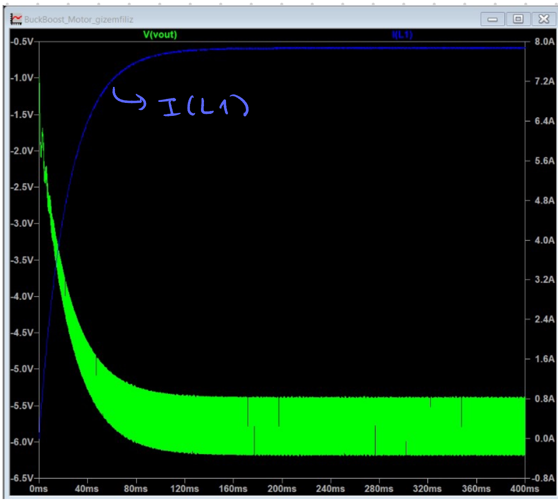
* D=0.5

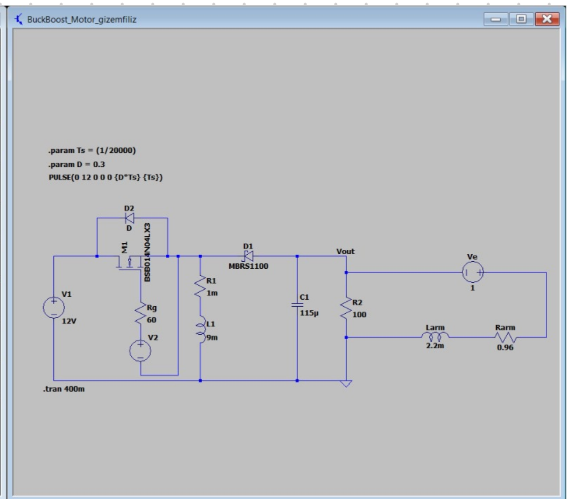




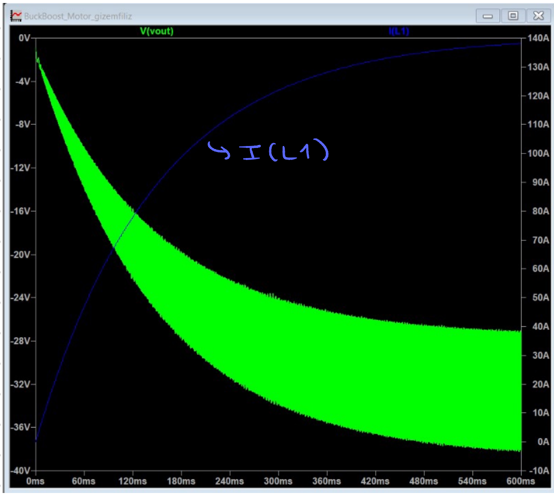
↳ Ve=1V resulted in an extreme increase of Voltage ripple, It become 3.7485V. This Vibrations may cause hardware to break. In order to overcome this issue, we may increase capacitor value or increase

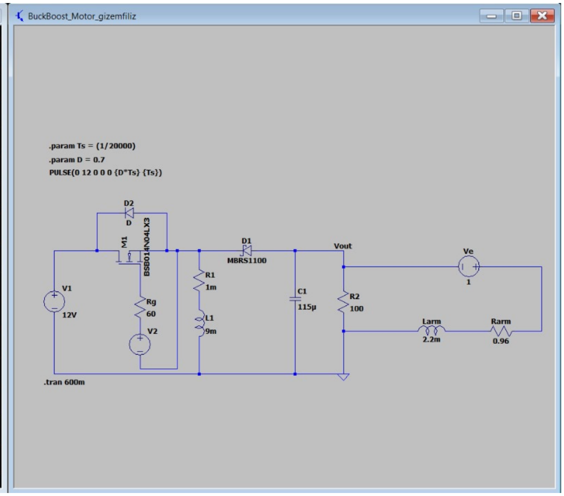
* D=0.3





* D = 0.7



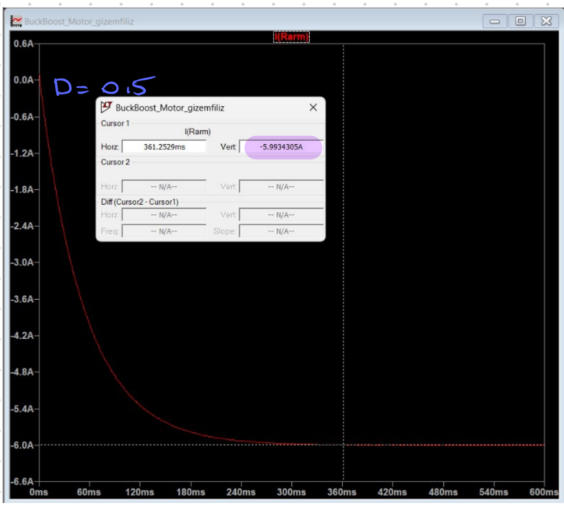


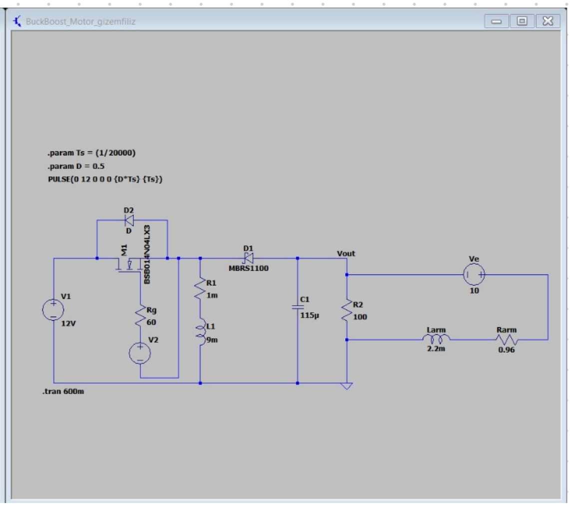
* Developed torque $T_e = k_m i_a$, Induced voltage $V_e = k_e \omega$
where $k_m = 0.5 \frac{N \cdot m}{A}$, $k_e = 0.5 \frac{V \cdot s}{rad}$, i_a is the armature current, and ω is the motor speed.

Given $\omega = 20 rad/s$, find Ve. Measure the resulting armature current to calculate the torque.

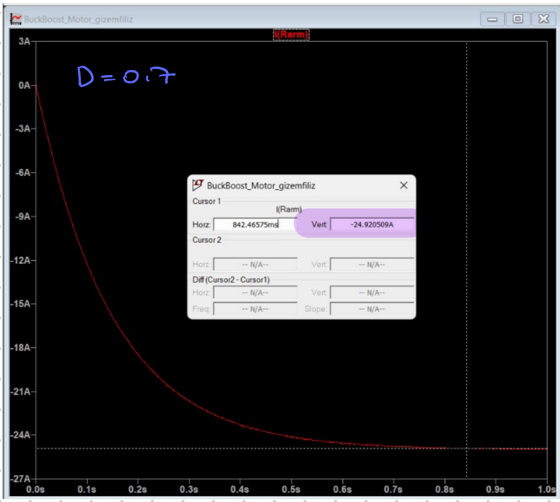
Do the same for $\omega = 10 rad/s$.

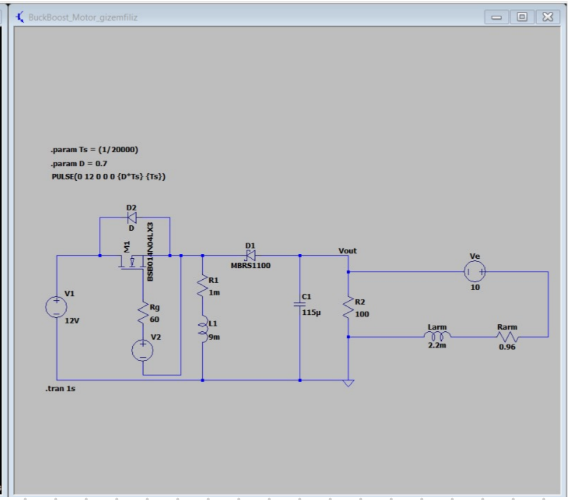
$\omega = 20$ rad/s $\Rightarrow$ $V_e = 0.5 \frac{V.s}{rad} \times 20 \frac{rad}{s} = 10$ V





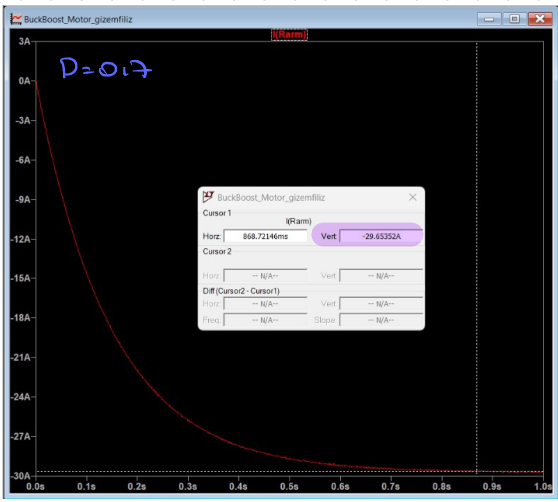
↳ $I_{arm} = 6A$ $\Rightarrow$ $T_e = 0.5 \frac{N.m}{A} \times 6A = 3$ N.m

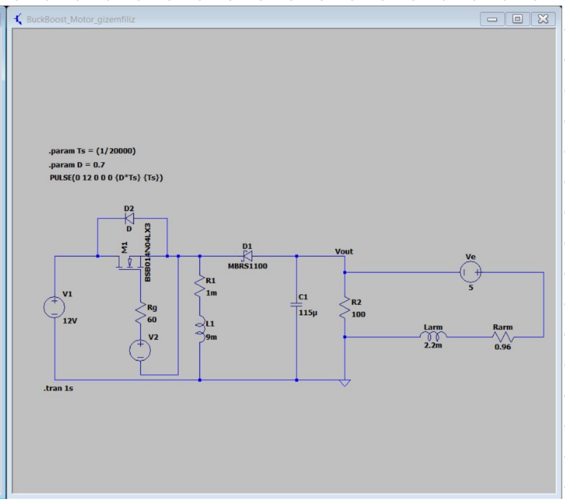




↳ $I_{arm} = 24.92\,A \Rightarrow \tau_e = 0.5\,\frac{N.m}{A} \times 24.92\,A = 12.46\,N.m$

$\omega = 10\ rad/s \Rightarrow V_e = 0.5\,\frac{V.s}{rad} \times 10\,\frac{rad}{s} = 5V$



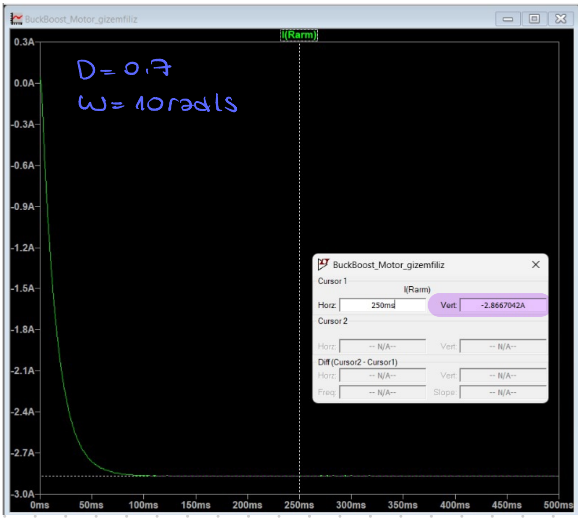


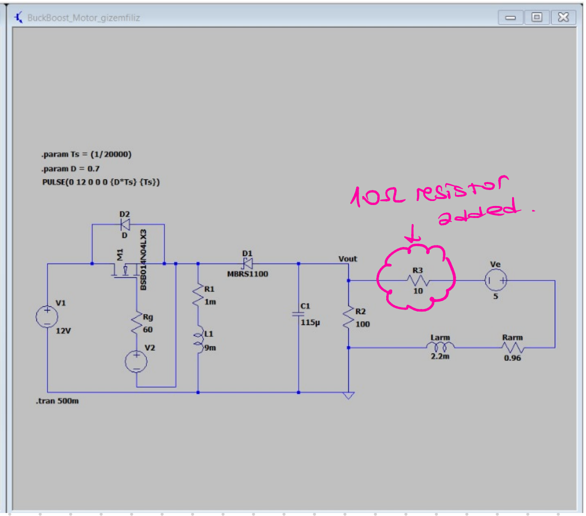
↳ $I_{arm} = 29.6535A \Rightarrow \tau_e = 0.5\,\frac{N.m}{A} \times 29.6535A = 14.8267\ N.m$

* The motor is rated for 5A current max. What changes can be made to protect the motor? What is the tradeoff?

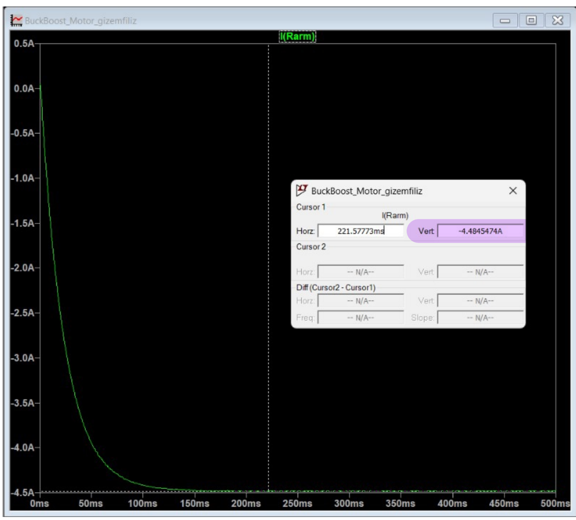
If we limit the motor current to maximum of 5A, we will encounter a limit on the motor's torque output too.

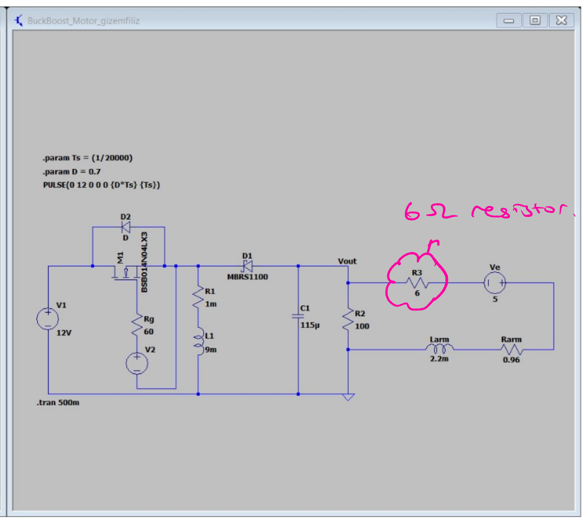
↳ we can achieve this by adding a resistor to armature setup.





Armature current is reduced to 2.8667A by adding 10Ω resistor to armature setup.





with 6Ω resistor, armature current became 4.48A.

(without additional R)

↳ $I_{arm} = 29.6535A \Rightarrow \tau_e = 0.5 \frac{N.m}{A} \times 29.6535A = \underbrace{14.8267\ N.m}$

(with R)

↳ $I_{arm} = 4.48A \Rightarrow \tau_e = 0.5 \frac{N.m}{A} \times 4.48\ A = \underbrace{2.24\ N.m}$

⇒ Adding R might protect the motor under high load conditions, however limiting armature current result in reduced torque and speed. Thus, limits the motor's operational capacity. We may prefer this strategy to reduce the risk of damaging circuit components and the motor.