EEE223 Assignment 2

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1 Data

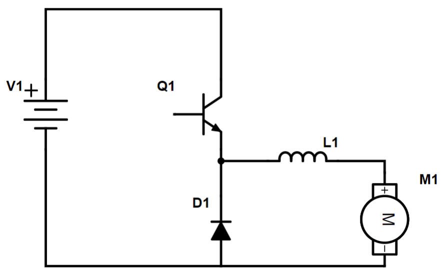

Figure 1: Chopper Motor controller diagram

Symbol	Value
V_1	60V
L	4mH
ϕ	0.008Nm/A
Q_1	0.8V
D_1	1V
R_{M1}	0.1Ω

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2 Section A:

Upon initial switching (transience) the inductance of the armature will always resist current change therefore acting as a current source (M1,M3). When a transistor is off it acts like an open circuit and therefore can be excluded except from the case where the transistor has just turned off meaning the inductor is trying to force current through the circuit and the diode allows this to occur without creating huge voltages. When a diode or transistor is on there is always a small voltage drop over it modeled by a voltage source in the diagram as shown.

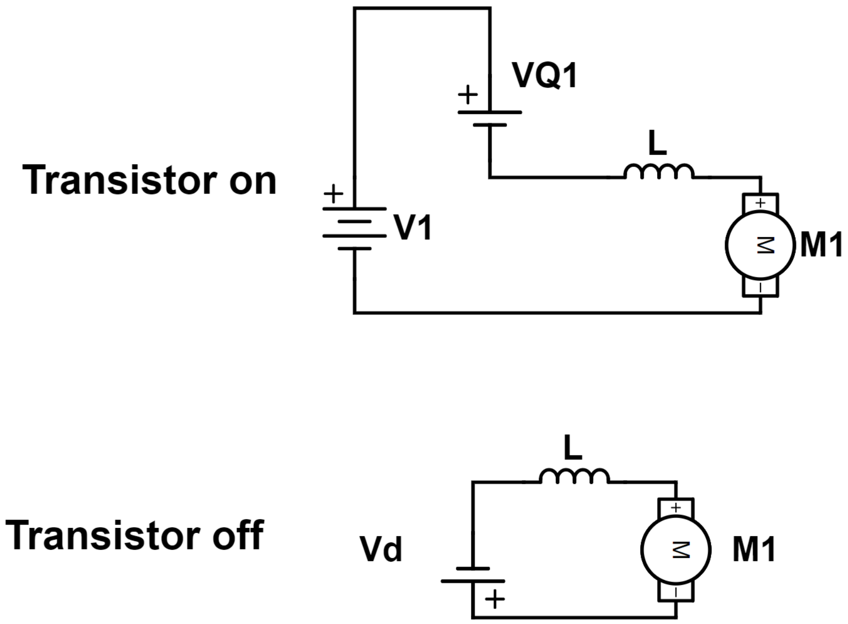

Figure 2: Diagram of transistor when on and off

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3 Section B:

First of all we calculate the value for average winding voltage by using equation 1. For this we need the desired rotational velocity and flux linkage. We are given the flux linkage directly seen in the table. We want a rotational velocity of 2000RPM and therefore convert this into radians to give 16.76V average.

$$V_a = \Psi\omega \tag{1}$$

We also know that when the motors current is taken from the battery a 0.8V drop occurs over the transistor giving us 59.2V supply. Equation 2 is created by looking at the graph in section C seeing that the average is given by $V_a = \frac{V_p t_{on} - V_d t_{off}}{T}$ where V_a is the average voltage and re-arranging using $T = t_{on} + t_{off}$ where T is $\frac{1}{f}$ given by 25mS.
Using the defined values we get that $t_{on} = 73.5\mu S$

$$t_{on} = \frac{T(V_a + V_d)}{V_p - V_d} \tag{2}$$

Knowing that $t_{on} = 73.5\mu S$ we can then work out the duty cycle and time off using $d = \frac{t_{on}}{T}$,$T = t_{on} + t_{off}$ respectively where d is the duty cycle (percentage of time on) which works out to 30%.

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4 Section C:

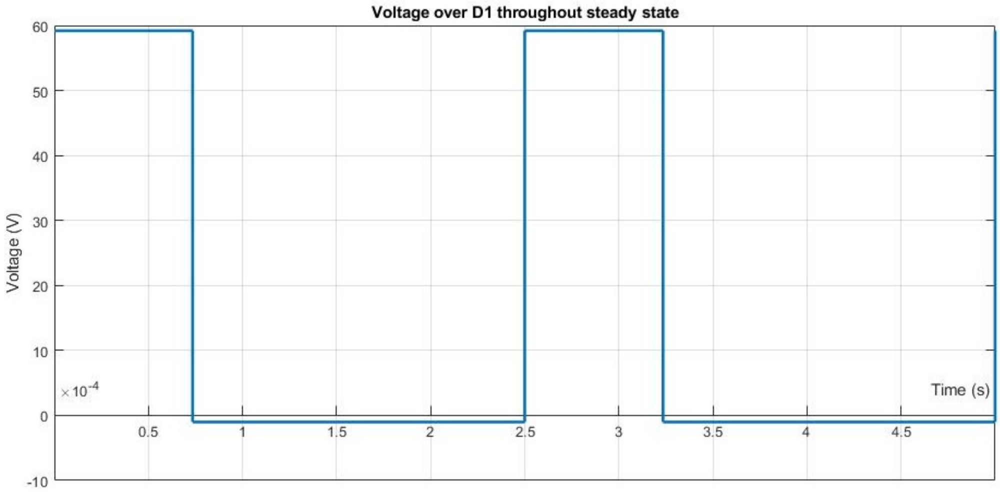

Figure 3: PWM waveform present over diode during normal use

The Matlab code for this graph can be seen in references Section.

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5 Section D:

To begin we use equation 3 and the values given to immediately calculate the average current needed of $2.5A$.

$$T_m = \Psi I \tag{3}$$

Next we look at equation 4 and see that this could be used to calculate our new time constant but unfortunately this equation works based off the fact that when the system is off the voltage is 0 but in our case the voltage is -1 and so we can use the equations $V_a = V_p t_{on} - V_d t_{off}$ and $T = ton + toff$ to substitute in and re-arrange to give us equation 5.

$$I_a = \frac{\frac{\tau}{T} V_p - V_A}{R_{M1}} \tag{4}$$

$$t_{on} = \frac{T(I_a R_m + V_A) + V_d T}{V_p + V_d} \tag{5}$$

Using all of the values supplied into equation 5 gives a value of $74.7\mu S$ which makes sense as when a load is added more voltage would be needed to supply the higher demand in current and this higher voltage comes from the higher duty cycle of the PWM.
To then find the ripple current we can use equation 6 to give us $\Delta I = 0.775$

$$\Delta I = \frac{V_p t_{on}(1 - \frac{t_{on}}{T})}{L} \tag{6}$$

The maximum and minimum can be calculated logically as the max will be the average plus half the ripple and min the average minus half the ripple giving values as such:
$I_{min} = 2.89$
$I_{max} = 2.11$

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6 Section E:

If we want to find the maximum operating frequency then we must work out first of all when our system is at its peak current ripple. To do this we can use the equations $V_a = \frac{V_p t_{on} - V_d t_{off}}{T}$ and $\Delta I = \frac{V_a(T - t_{on})}{L}$ where $d = \frac{t_{on}}{T}$ to give us

$$\Delta I = \frac{d^2(-V_p - V_d) + d(V_p + 2V_d) - V_d}{L} \tag{7}$$

Differentiating this with respect to d at 0 (minima/maxima) gives the equation $0 = \frac{2*d(-V_p - V_d) + V_p + 2V_d}{L}$ This can be re-arranged to show that $d = \frac{V_p + 2V_d}{2(V_p + V_d)}$ using our values for the diode and peak voltage gives that the peak duty cycle is $d = 50.8\%$ which makes sense as it would be 50% without the diode reverse voltage and so we must have the voltage on for slightly longer to counteract this diode voltage.

Knowing this fact we can then find out the frequency to sustain such ripple at the 50.8% Maxima by using the equation $\Delta I = \frac{t_{on}(V_p - V_a)}{L}$ and the $V_a = \frac{tonV_p - V_d t_{off}}{T}$ equation and the definition of duty cycle ($d = \frac{t_{on}}{T}$). This gives a values of $V_a = 29.58V$ and $t_{on} = 81\mu S$ which therefore means a frequency of $6271Hz$ is needed

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7 Section F:

Using the value of 4kHz for PWM frequency and including the voltage drop of the diode ($V_a = \frac{t_{on}V_p - t_{off}V_d}{T}$) the graph sown can be formed using ohms law, $T = \psi I$ and $V_a = \psi\Omega$

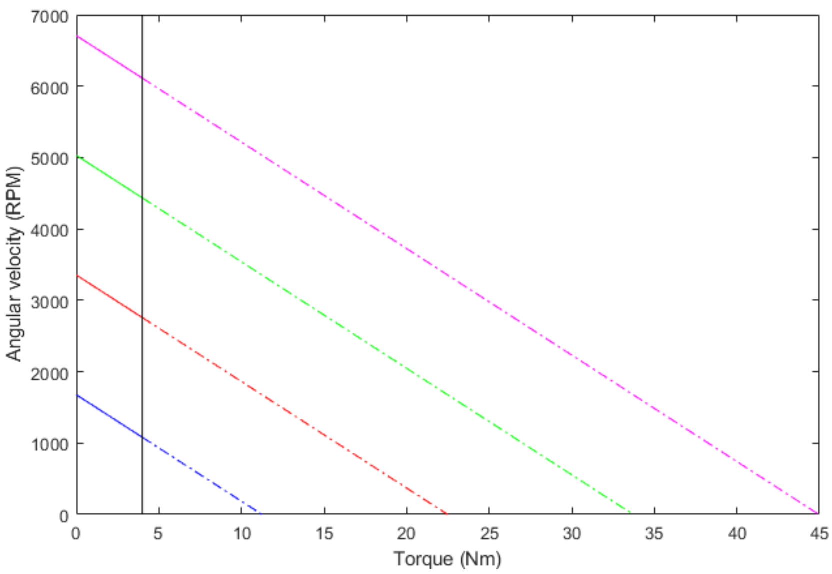

Figure 4: Angular velocity Vs Torque graph

In the figure the black line stands for our rated current. anything within rated current is in solid whereas outside of the rated is in the dot-dash style.

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8 Section G:

The basic layout for a 4 quadrant driver is a H-Bridge where transistors are paired together to create current paths (Q1 paired with Q4 and Q2 paired with Q3). A dead time is used to make sure transistor pairs aren't both on which would short the supply but this dead time leaves the inductor charged with no path to discharge which would create high voltage spikes that could damage the transistors or motor. To protect the H-Bridge diodes are in place to create a low impedance path to discharge without damage. Capacitors may be used in parallel to the supply to reduce spikes of current taken from the supply but assuming a perfect power supply these can be omitted.

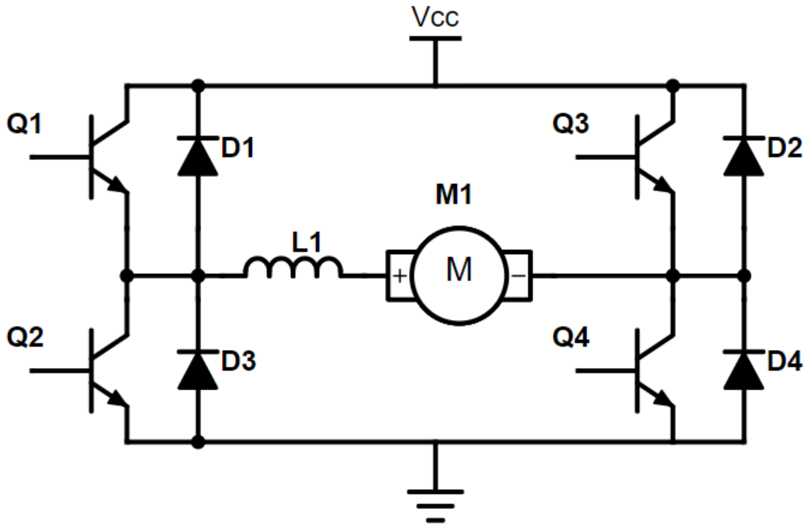

Figure 5: 4 Quadrant driver (H-Bridge)

By comparing the voltages produced by having the two pairs on respectively and taking the voltage over the motor we get that $V_a = (\frac{2\tau}{T} - 1)(V_{cc} - 2 * V_d)$, therefore for 0V average we simply make $\frac{2\tau}{T} = 1$ aka $d = 0.5$ where d is the duty cycle. Knowing this we can also work out the current ripple using $\Delta I = \frac{t_{on}(V_p - 2V_d)}{L}$, which can be derived using the inductor voltage equation. This gives a current ripple of $\Delta I = 1.825A$.