IGEE 401 Power Electronics

Lab Report 3- DC-DC Converter

Group 213

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1.1 Objectives

The objective of this experiment is to study the operation of a one quadrant (buck) and of a two quadrant DC-DC converter in an open loop. Additionally, the lab investigates the performance of these two converters when used in a DC motor drive.

1.2 Preliminary Calculations

1). Compute the shaft speed and armature current of the DC motor at no-load, when a 1-quadrant buck DC-DC converter is used and operates with D = 0.8 and 0.4

Since there is no load, the armature current is 0 under ideal conditions.

For D = 0.8

$$W_m = \frac{V_a}{k\Phi} = \frac{0.8\ \cdot 280}{1.23} = 182.11\, rpm$$

For D = 0.4

$$W_m = \frac{V_a}{k\Phi} = \frac{0.4\ \cdot 280}{1.23} = 91.06\, rpm$$

2). Compute the shaft speed and the armature current of the DC motor when the load torque is equal to 10 Nm and -10 Nm. Assume that the DC-DC converter operates with D = 0.8.

For $T_{ind} = 10\ Nm$

$$I_a = \frac{T_{ind}}{k\Phi} = \frac{10}{1.123} = 8.1301\ A$$

$$W_m = \frac{V_a}{k\Phi} - \frac{R_a}{(k\Phi)^2} \cdot T_{ind} = \frac{0.8\ \cdot 280}{1.23} - \frac{0.5}{(1.23)^2} \cdot 10 = 178.81\, rpm$$

For $T_{ind} = -10\ Nm$

Since it's a one quadrant converter, the machine cannot work when the armature current is negative.

3). Repeat the previous calculation for the DC motor driven by a 2-quadrant DC-DC converter.

For $T_{ind} = 10\ Nm$

$$I_a = \frac{T_{ind}}{k\Phi} = \frac{10}{1.123} = 8.1301\ A$$

$$W_m = \frac{V_a}{k\Phi} - \frac{R_a}{(k\Phi)^2} \cdot T_{ind} = \frac{0.8\ \cdot 280}{1.23} - \frac{0.5}{(1.23)^2} \cdot 10 = 178.81\, rpm$$

For $T_{ind} = -10\ Nm$

$$I_a = \frac{T_{ind}}{k\Phi} = \frac{-10}{1.123} = -8.1301\ A$$

$$W_m = \frac{V_a}{k\Phi} - \frac{R_a}{(k\Phi)^2} \cdot T_{ind} = \frac{0.8\ \cdot 280}{1.23} - \frac{0.5}{(1.23)^2} \cdot (-10) = 186.18\ rpm$$

1.3 Simulations

1.3.1 1-Quadrant Buck Converter

b) The simulation of operation with variable duty cycle at no load for 1 quadrant buck converter is shown in the figure below.

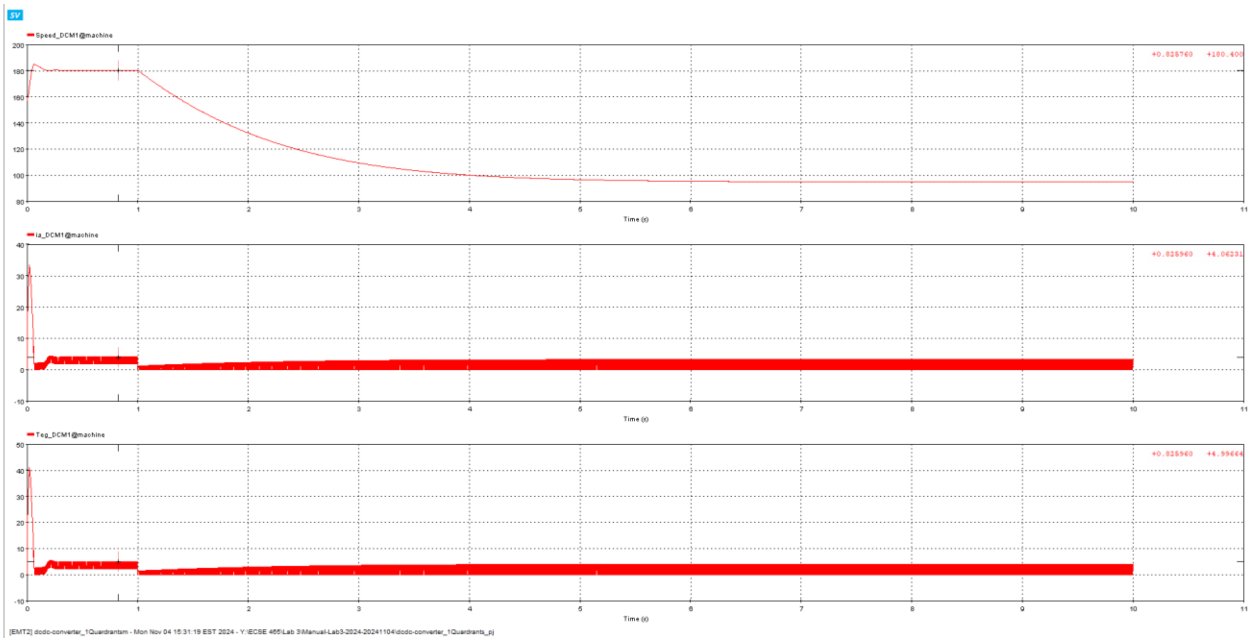

Figure 1 Simulation of speed, armature current and torque for D = 0.4 and 0.8

c) There is not a big difference between the load values between the two duty cycles as the motor is operating in no-load condition. However, we can see that the load and torques with D = 0.4 are half of the values in the condition of D = 0.8. This is due to the difference in output voltage when varying the duty cycle, where

$$V_d * D = V_o$$

e). The simulation of operation with constant duty cycle and variable load torque of quadrant buck converter is shown in the figure below.

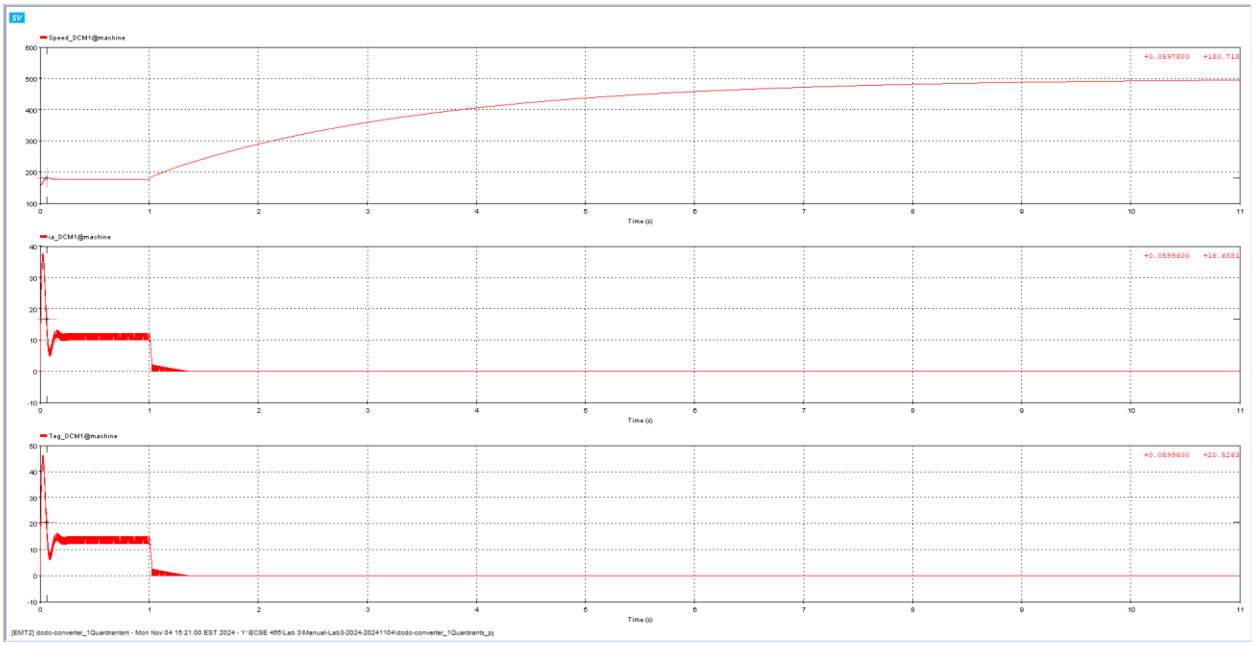

Figure 2 Waveform for operation with constant duty cycle and variable load torque

1.3.2 2-Quadrant DC-DC Converter

b). Simulation of the waveform is shown in the figure below.

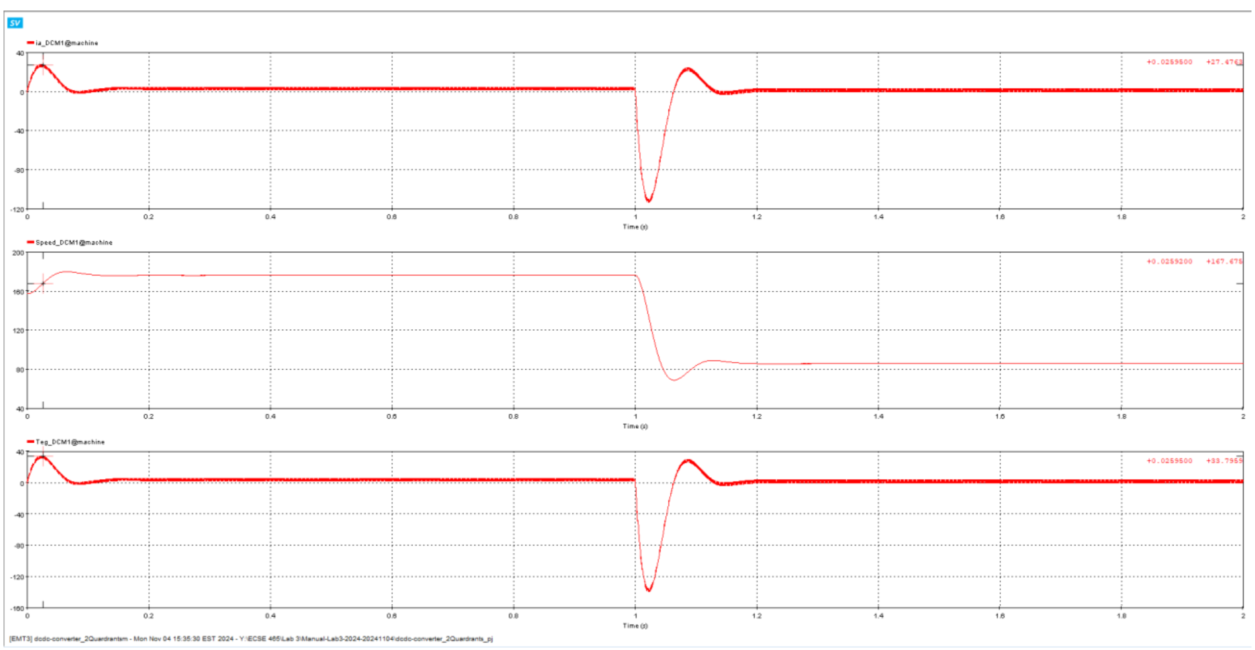

Figure 3 Waveform for operation with variable duty cycle at no-load

c) Same as above, in 1.3.1.c)

e). Simulation waveform

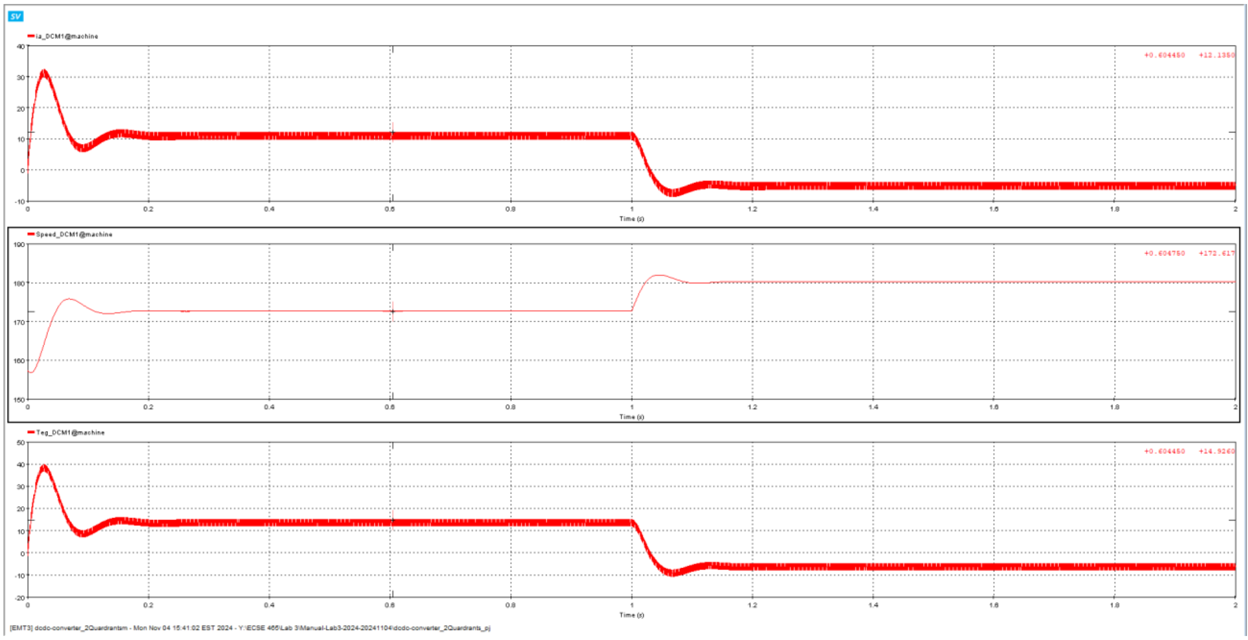

Figure 4: Waveform for operation with constant duty cycle and variable load torque

	1-Quadrant DC-DC converter		2 Quadrant DC-DC Converter	
	D= 0.8	D = 0.4	D = 0.8	D = 0.4
Settling time (ms)	0.16126	4	0.126	0.178
Ω m (rad/s)	180.4	94.66	175.907	85.53
I_a (A)	2.89547	1.52370	2.8605	1.3907
Torque	3.56142	1.87415	3.51845	1.71056

Table 1 Operation with Variable Duty Cycle (D) at no-load

	1-Quadrant DC-DC converter		2 Quadrant DC-DC Converter	
	T = 10	T = -10	T = 10	T = -10
Settling time (ms)	0.173780	8	0.178020	0.13425
Ω m (rad/s)	177.114	497.398	172.617	180.169
I_a (A)	10.996	-6.79e-6 (close to 0)	10.937	-5.20053
Torque	13.5250	-1.9295e-6 (close to 0)	13.4528	-6.396

Table 2 Operation constant duty cycle (D = 0.8) and variable load torque

1.4 Questions

1). **Why is the settling time of the 1-quadrant converter larger than that of the 2 quadrant converter when there is a step variation in D and the DC motor operates at no load? Why are the settling times of the two converters similar during the start-up transient with D = 0.8 and load torque equal to 10 Nm?**

a). The 1-quadrant DC-DC converter consists of a single switch and a single free-wheeling diode, allowing it to control motor speed in only one direction of rotation by varying the magnitude of the DC voltage applied to the armature of the DC motor. It provides unidirectional current and torque and lacks the ability to actively control or reverse the torque. The excess energy can only be dissipated passively through internal resistances. This limitation results in a slower dynamic response and a higher settling time for step variations. In contrast, the 2-quadrant DC-DC converter employs twice as many components in an inverter leg configuration, enabling it to both motor and brake the DC machine in one direction of rotation. During braking operations, it can transfer kinetic energy from the rotating masses back to the DC source. This capability allows for bidirectional current flow, enabling the converter to dynamically brake or accelerate the motor more effectively, which results in a shorter settling time.

b). When the load torque is applied, both converters operate in their active regions, and their dynamic behavior converges. The applied load torque reduces the system's reliance on bidirectional control because the motor's operation is dominated by its load torque and input voltage. The difference between converters becomes negligible under these conditions, leading to similar settling times.

2). **Consider the case of the DC motor supplied by the 2-quadrant DC-DC converter with D= 0.8. Why does the shaft speed for a negative load torque is larger than that for no-load? What is the meaning of a negative armature current when the motor operates with a negative load torque?**

a). A negative load torque implies that the external load opposes the motor's natural rotation, acting as a braking torque. In such situation, the motor works as a generator, converting kinetic energy into electrical energy, which is fed back to the supply. From the formula in the pre-lab session, we see that shaft speed decreases as torque increases. For a negative torque, the second term $-\frac{R_a}{(k\Phi)^2} \cdot T_{ind}$ becomes positive, adding to the shaft speed. Thus, shaft speed increases when the load torque is negative for a 2-quadrant converter. In contrast, for no load condition, the second term has no contribution, resulting in a lower speed compared to the case with negative torque.

b). The armature current determines the direction of power flow in the motor. When the induced torque is negative, the motor generates electrical energy instead of consuming it. This causes the current to reverse direction, resulting in negative armature current. In this mode, the motor converts mechanical energy from the shaft into electrical energy and sends it back, facilitated by the bi-directional capability of the 2-quadrant DC-DC converter.

3). Consider the case of the DC motor supplied by the 1-quadrant DC-DC converter with D = 0.8. Why does the shaft speed keep increasing and the armature current is zero for a negative load torque?

The 1-quadrant DC-DC converter can only provide unidirectional current and torque. It cannot handle regenerative breaking or reverse power flow from the motor back to the source. For a negative load torque, the motor becomes uncontrolled. The converter cannot control the torque applied to the shaft. The kinetic energy of the system and external negative torque contribute to the acceleration of the motor. For a negative load, the load drives the shaft rather than motor supplying energy to the load. The back-emf of the motor exceeds the applied armature voltage. The motor no longer draws current from the supply because the converter cannot process the generated energy resulting in zero armature current. The system essentially freewheels with no current drawn due to the unidirectional nature of the 1 quadrant converter.

1.5 Conclusion

This lab demonstrated the operational differences between 1-quadrant and 2-quadrant DC-DC converters in DC motor drives. The 1-quadrant converter, with its unidirectional current flow, showed limitations in controlling torque and speed, leading to higher settling times and uncontrolled acceleration under negative load torque. In contrast, the 2-quadrant converter enabled bidirectional current flow, allowing for dynamic braking, efficient energy recovery, and shorter settling times. These results highlight the advantages of 2-quadrant converters for applications requiring precise motor control and regenerative braking.