NATIONAL UNIVERSITY OF SINGAPORE
Department of Electrical and Computer Engineering
AY 2025-26
EE4502 Project-Based Lab Experiments

Experiment 1: DC Drive System

Main objective:

In this part of the mini project, DC drive system will be investigated. The experiment starts with the unregulated AC power source such as utility supply mains converted into DC power source and then supplies to the two-quadrant, Class-C converter to drive a DC motor. In the midst of these conversion processes, important factors like dynamic response of the drive system, harmonics and power factor would be evaluated. The two-quadrant operation of the DC drive system incorporating ***forward motoring*** and ***forward braking*** mode of operations would also be investigated. In the last part of the experiment, closed-loop speed control of the DC drive system will be investigated.

Discussions

Introduction to Chopper-Fed DC Motor Drive for Two Quadrant Operation

A **buck (step-down)** chopper converts a fixed dc input voltage to a *lower* variable output dc voltage. Similarly, a **boost (step-up)** chopper converts a fixed dc input voltage to a *higher* variable dc output voltage. When these two converters are connected together and it is possible to create a two-quadrant (CLASS-C) converter. The converter allows **two-quadrant operation** as the current can flow in either direction as shown in Figure .1.

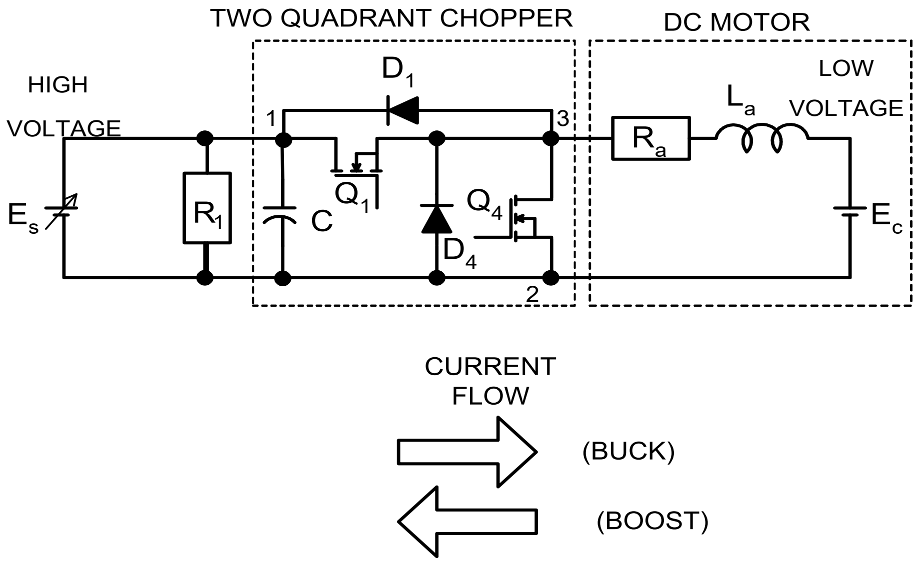

Figure.1: A two quadrant converter driving a dc motor

In Figure.1, switch Q_1 and diode D_4 form the buck converter and switch Q_4 and diode D_1 compose the boost converter. The addition of the boost section to the buck converter circuit provides braking torque capability by allowing the regenerated energy to be sent back towards the source.

When the switch Q_4 turns ON, the dc motor back-emf contributes to reversing the armature current, converting mechanical energy into electrical form. When the switch Q_4 is turned OFF, energy stored in the armature inductor together with the rotational kinetic energy is sent back to the source through diode D_1, as switch Q_1 is being blocked. Energy is then dissipated across the power resistor, R_1. This resistor limits the dc link voltage to be maintained within the allowable limits. Please take note that no energy is sent back to the ac power source.

DC Motor Characteristic Equations:

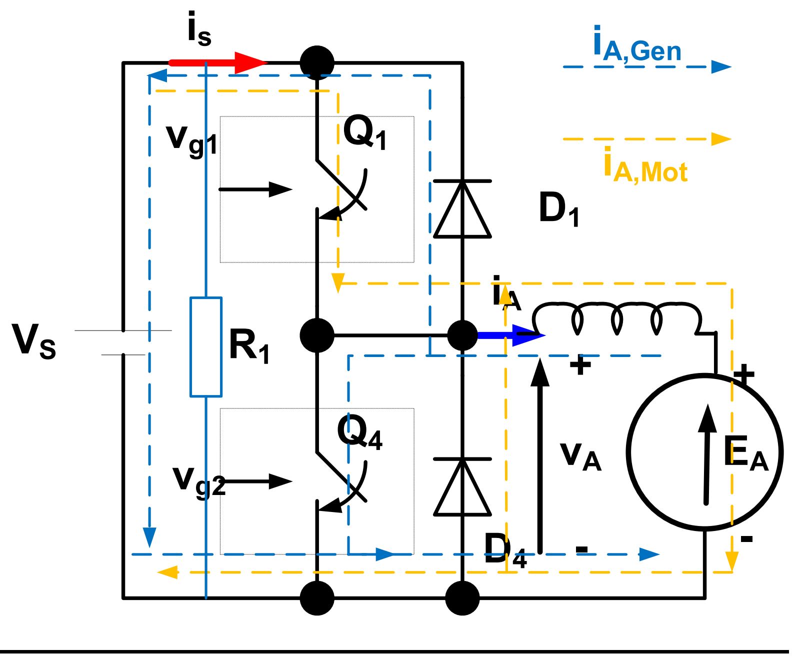

Figure 2: A two quadrant converter driving a dc motor

$$E_a = k\phi_f \omega_m = K_E \omega_m$$
$$T_e = k\phi_f I_a = K_T I_a$$
$$K_T = K_E = k\phi_f = kL_{af} I_f$$
$$V_a = E_a + I_a R_a$$
$$\omega_m = \frac{E_a}{K_E} = \frac{V_a - I_a R_a}{K_E} = \frac{V_a}{K_E} - \frac{T_e R_a}{K_E^2}$$

where, E_a is the back emf, V_a is the armature voltage, ω_m is speed, I_a is armature current, R_a is armature resistance, L_f is the mutual inductance, T_{em} is the electromagnetic torque, and I_f is the field current. Neglect the brush voltage drop.

<u>DC motor parameters</u>

1. Armature resistance R_a : 30 Ω
2. Armature inductance L_a : 0.39 H
3. Inertia J: 0.00xx Kg-m^2
4. Field Voltage V_f : 240 V
5. Mutual inductance L_m: 1.8072 H
6. Field resistance R_f : 697 Ω
7. Field inductance L_f : 14.9 H
8. Initial speed : 0 rpm
9. Viscous friction coefficient B_m: 0 N-m-s
10. Coulomb friction torque T_f : 0 N-m

(The value of 'xx' for item no. 3 in the above parameters is derived from the last 2 digits of the student ID)

<u>Simulations</u>

<u>Simulation 1: Introduction to Chopper-Fed of DC Motor Drive under open-loop control</u>

Use the "dcmotor_openloop.slx" file for executing the Simulink program. In this exercise, you would study how the two-quadrant chopper can be used to drive a dc motor. Subsequently, the performance of the dc motor drive system under step-change in reference speed or step-change in load-torque command could be examined.

~~1)~~ When the duty cycle is fixed at 0.5 and no external mechanical load torque is applied, observe the corresponding motor torque, speed, current and voltage waveforms and provide detailed explanations of your observations.

2) Investigate the performance of the drive system when the *duty cycle* is step-changed from 0.5 to (0.5+α) at t = 2 sec and from (0.5+α) to (0.5-β) at t = 4 sec. Please note that no external mechanical load is applied. (For values of α and β please refer Table 1 and Table 2)

(The value of ‘X’ is the last digit in the student ID of the student)

Table 1: Duty cycle value to be adopted at t=2 sec

Value of X	α
$0 \leq X \leq 2$	0.1
$3 \leq X \leq 6$	0.2
$7 \leq X \leq 9$	0.3

(The value of ‘Y’ is the second last digit in the student ID of the student)

Table 2: Duty cycle value to be adopted at t=4 sec

Value of Y	β
$0 \leq Y \leq 2$	0.3
$3 \leq Y \leq 6$	0.2
$7 \leq Y \leq 9$	0.1

3) Investigate the performance of the drive system when the *load torque* is step-changed from 0 to 2α N.m at t = 2.0 sec and from 2α N.m to β N.m at t = 4.0 sec. Please note that the duty cycle is kept constant at 0.5.

<u>Note:</u> Use the Matlab file ‘motoropenplot.m’ in the Matlab window to observe the motor speed, torque, voltage and current waveforms for above three simulations.

Simulation 2: Introduction to Chopper-Fed DC Motor Drive with Closed-loop Outer Speed Control Loop and Inner Current Control Loop

Use the "dcmotor_closedloop_inner_twoloop.slx" file for executing the Simulink program. In this exercise, you would study the effect of introducing an inner current loop.

1) Run "design_pi_con_currentloop.m", file to obtain the PI controller parameters for inner current control loop, use the same parameters (**please enter the DC Machine parameters**) for outer speed control loop as calculated in simulation-2.

   Note: Calculate $V_{dc}=\frac{3V_{m,L-L}}{\pi}$; where, $V_{m,L-L}$ is the peak line-to-line voltage of the three-phase source and substitute switching frequency $f = 2000\ Hz$.

2) When the reference speed is fixed at '*R*' rpm and no external mechanical load is applied, observe the corresponding motor torque and speed waveforms and explain the results.

3) Investigate the performance of the drive system when the load torque has step-changed by a disturbance of 0.5 N.m at t = 2 sec. Please note that the reference speed is kept constant at '*R*' rpm.

(The value of 'Z' is the second last digit in the student ID of the student)

Table 3: Values of reference speed to be adopted for Simulation 2

Value of Z	*R*
$0 \leq Z \leq 2$	650
$3 \leq Z \leq 6$	800
$7 \leq Z \leq 9$	950

Note: Use the Matlab file 'motorcloseplot.m' in the Matlab window to observe the motor speed, torque, voltage and current waveforms for above three simulations.

The details of the design method are given in "**Expt1_Controller design Ref.pdf**" file.

Note: If inner current loop is introduced the speed response becomes less oscillatory and becomes faster.

Experiments

Introduction to Speed Control of Chopper-Fed DC Motor Drive for two quadrant operation (forward motoring and forward braking).

- **Equipment**

  - Power Supply (8821-2A)
  - Prime mover / Dynamometer (8960-15)
  - DC Motor / Generator (8211-0A)
  - Speed Sensor / Tachometer (8931-00)
  - Power Diode Module (8842-1A)
  - IGBT Chopper / Inverter Control Unit (8837-AA)
  - P.I.D. Controller (9034-00)
  - Resistive Load (8311-0A)
  - Smoothing Inductor (8325-15)
  - DC Voltmeter/Ammeter (8412-15)
  - Current/Voltage Isolator (9056-15) – 2 sets
    with ±15V/+5V Power Supply (8840-0A)
  - 4-channel Oscilloscope

CAUTION!

High voltages are present in this laboratory experiment! Do not make or modify any banana jack connections with the mains power supply ON.

1-A. Open loop speed control of the DC motor

1. Switch off the power supply to Current/ Voltage Isolator module. Turn the voltage control knob counter-clockwise completely to 0% and then set the mains power switch on the power supply to the marked *O* (off) position.

2. Using the output of the three-phase diode bridge rectifier as the main DC power supply for the dc motor driver circuit, connect the driver circuit as shown in Figure.3

3. Ensure the voltage control knob in the Power Supply module is at 0% position. Switch on the incoming supply, 24-V ac power and ± 15V DC supply.

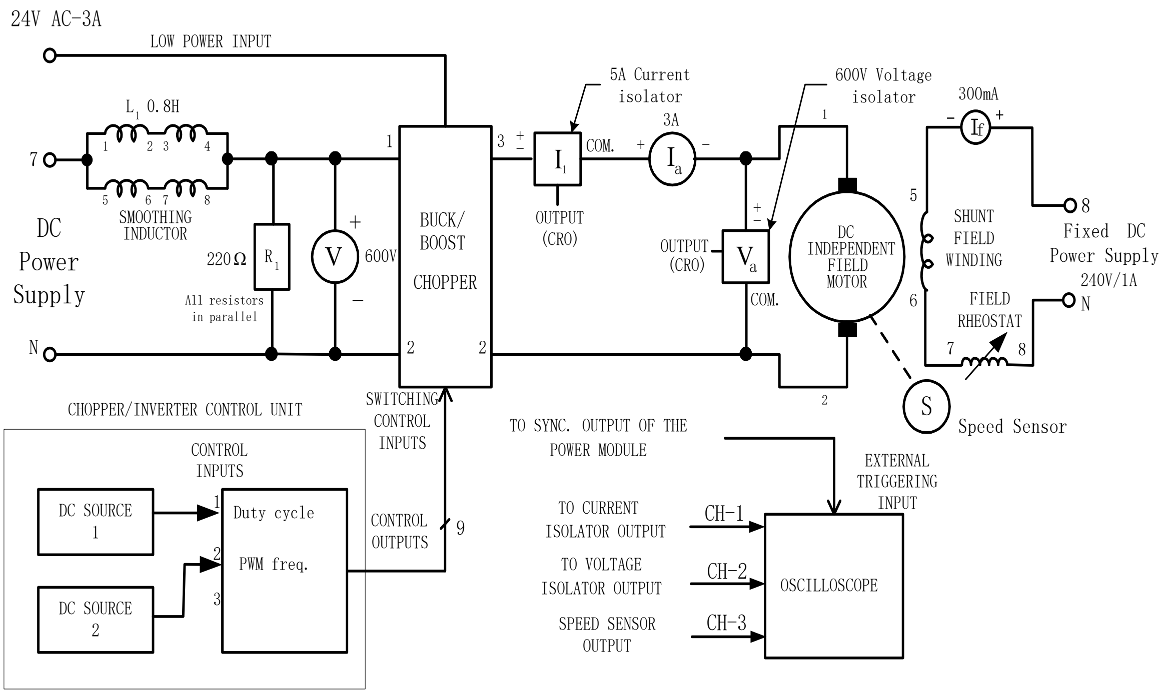

Figure.3: Circuit of a two quadrant converter driving a dc motor drive system

4. Adjust the parameters on the following modules/equipment: -
   - Keep all the ground potentials at the common point (**Control signals, 24V and +/- 15V power supply only**).
   - Power IGBT modules
     - Switch the interconnections switches to OFF position
   - Chopper/Inverter Unit
     - DC SOURCE 1: MINIMUM (duty cycle)
     - DC SOURCE 2: MAXIMUM (PWM frequency)
     - MODE: CHOP. PWM

- Oscilloscope
  - Adjust the oscilloscope sensitivity and time base to appropriate values

5. Set the DC Motor/Generator field current to its nominal value (300 mA) using the field rheostat.

6. Adjust the voltage control knob in the Power Supply to 100% position. Make sure the input voltage to the chopper (the output voltage of the three-phase diode bridge rectifier) increases to about V_f = 240V.

7. Vary the duty cycle of the Chopper slowly to vary the speed of the dc motor. Adjust the oscilloscope to see the DC motor armature current, voltage and speed which correspond to the PWM cycles. Take a printout of the oscilloscope waveforms for your report. Repeat this for three different points covering the whole range of duty cycle.

Question 1. Explain the relationship between the PWM duty cycles and the DC motor voltage and speed. Try to discuss about how the current changes when increasing speed or decreasing the motor speed.

8. Set the duty cycle at 30%. Now, load the motor manually by adjusting the load setting of the dynamometer. Slowly increase the load setting and the effect on the motor speed. Take three to four points. Repeat this experiment for duty cycle at 50%.

Question 2. Plot the torque – speed characteristics of the motor for the two duty cycles and discuss about the nature these curves.

1-B. Study the effect of field current on the torque-speed characteristics of DC motor:

9. Turn the dynamometer load setting to minimum value.

10. (Under No load Conditions) Set the duty cycle to 50%. Adjust the field current to 150mA. Note down the speed of the motor. Repeat this experiment for field current of 200mA and 300mA.

11. (Under Loading Conditions). Set the field current to 300mA, and adjust the duty cycle to 50%. Now, load the motor manually by adjusting the load setting of the dynamometer. Slowly increase the load setting and the effect on the motor speed. Take three to four points. Repeat this experiment for field current at 150mA.

Question 3. Plot the torque – speed characteristics of the motor for two field currents and discuss about the nature these curves.

Report

For the reports, please follow the below instructions

Simulations:

1. Open Loop Control of DC Motor Drive
   a. Attach the motor speed, armature voltage waveform
   b. Attach the motor torque, armature current waveform
   c. Attach the armature voltage and armature current waveform
   d. Comment your observations (how changing duty cycle and load torque affects the armature voltage, armature current, torque and speed and why)

2. Closed Loop Control of DC Motor Drive – speed and current control loop
   a. Mention the speed and current control loop PID parameters used
   b. Attach the speed and torque waveforms
   c. Comment your observations on how changing the load torque affects speed and why?

Experiments:

1-A. Open Loop Control of DC Motor – effect of duty cycle on speed

   a. Attach three waveforms of speed variation with duty cycle
   b. Answer question Q1 and Q2 and comment your observations

1-B. Open Loop Control of DC Motor – effect of field current

   a. Attach torque-speed variation waveforms for two different field currents
   b. Answer Q3 and comment your observations

General instructions

- Do not report the result directly. Try to explain your results and the steps followed.
- Clearly state any additional assumptions that you have taken.
- Clearly mention the values adopted for variables in the above experiment (ex: Mention the value obtained for variable X near Table 1 with calculations).
- Mention the contribution of each member of the group to this experiment.