الكلية	كلية الهندسة
القسم	الكهرباء
المادة باللغة الانجليزية	Electrical Drives
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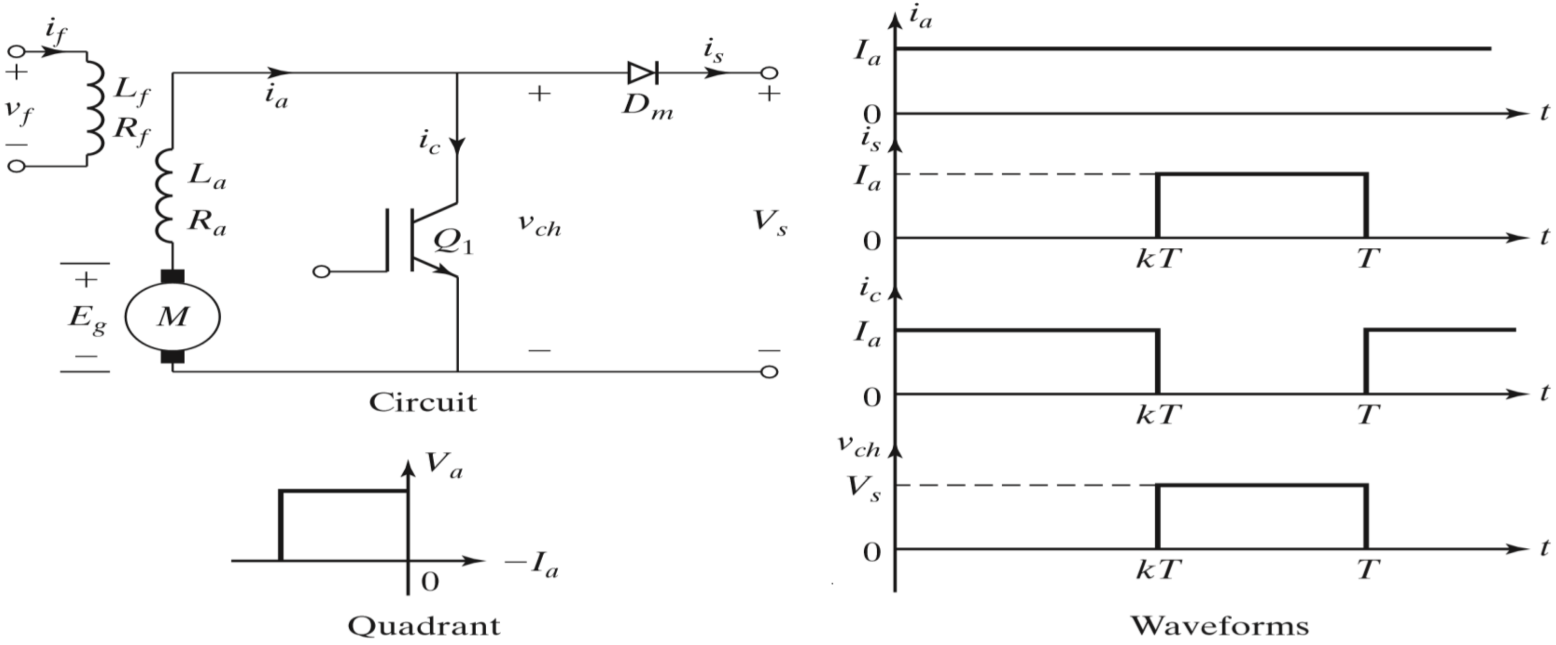
المصادر والمراجع	1) Mohummed Rashid" Power electronics circuits, Devices application" 4th edition, 2014 and
	2) Gopal K. Dubey " power semiconductor controlled Drives" 1st edition, 1989

Principle of regenerative brake control

In regenerative braking, the motor acts as a generator and the kinetic energy of the motor and load is returned back to the supply. The principle of energy transfer from one dc source to another of voltage is is call step up choppers. And this can be applied in regenerative braking of dc motors.

Let us assume that the armature of a separately excited motor is rotating due to the inertia of the motor(and load), and in case of a transportation system, the kinetic energy of the vehicle or train would rotate the armature shaft. Then if the transistor is switched on, the armature current rises due to the short-circuiting of the motor terminals. If the dc–dc converter is turned off, diode D_m would be turned on and the energy stored in the armature circuit inductances would be transferred to the supply, provided that the supply is receptive. It is a one-quadrant drive and operates in the second quadrant, Fig. 2 shows circuit diagram of regenerative break control.



Regenerative braking of dc separately excited motors.

The average voltage across the dc–dc converter is

$$V_{\text{ch}} = (1 - k)V_s$$

If I_a is the average armature current, the regenerated power can be found from

$$P_g = I_a V_s (1 - k)$$

The voltage generated by the motor acting as a generator is

$$\begin{aligned} E_g &= K_v I_f \omega \\ &= V_{\text{ch}} + R_m I_a = (1 - k)V_s + R_m I_a \end{aligned}$$

where K_v is machine constant and ω is the machine speed in rads per second. Therefore, the equivalent load resistance of the motor acting as a generator is

$$R_{\text{eq}} = \frac{E_g}{I_a} = \frac{V_s}{I_a}(1 - k) + R_m$$

By varying the duty cycle k, the equivalent load resistance seen by the motor can be varied from R_m to($V_s/I_a + R_m$) and the regenerative power can be controlled

The conditionsfor permissible potentials and polarity of the two voltages are

$$0 \leq (E_g - R_m I_a) \leq V_s$$

which gives the minimum braking speed of the motor as

$$E_g = K_v \omega_{min} I_f = R_m I_a$$

or

$$\omega_{min} = \frac{R_m}{K_v} \frac{I_a}{I_f}$$

and $\omega \geq \omega_{min}$. The maximum braking speed of a series motor can be found from

$$K_v \omega_{max} I_f - R_m I_a = V_s$$

or

$$\omega_{max} = \frac{V_s}{K_v I_f} + \frac{R_m}{K_v} \frac{I_a}{I_f}$$

and $\omega \leq \omega_{max}$.

The regenerative braking would be effective only if the motor speed is between these two speed limits (e.g., $\omega_{min} < \omega < \omega_{max}$). At any speed less than ω_{min}, an alternative braking arrangement would be required.

Although dc series motors are traditionally used for traction applications due to their high-starting torque, a series-excited generator is unstable when working into a fixed voltage supply. Thus, for running on the traction supply, a separate excitation control is required and such an arrangement of series motor is, normally, sensitive to supply voltage fluctuations and a fast dynamic response is required to provide an adequate brake control. The application of a dc–dc converter allows the regenerative braking of dc series motors due to its fast dynamic response.

A separately excited dc motor is stable in regenerative braking. The armature and field can be controlled independently to provide the required torque during starting. A dc–dc converter-fed series and separately excited dc motors are both suitable for traction applications.

principle of rheostatic Brake Control

In a rheostatic braking, the energy is dissipated in a rheostat and it may not be a desirable feature. In MRT systems, the energy may be used in heating the trains. The rheostatic braking is also known as dynamic braking. An arrangement for the rheostatic braking of a dc separately excited motor is shown in Fig. 3. This is a one-quadrant drive and operates in the second quadrant.

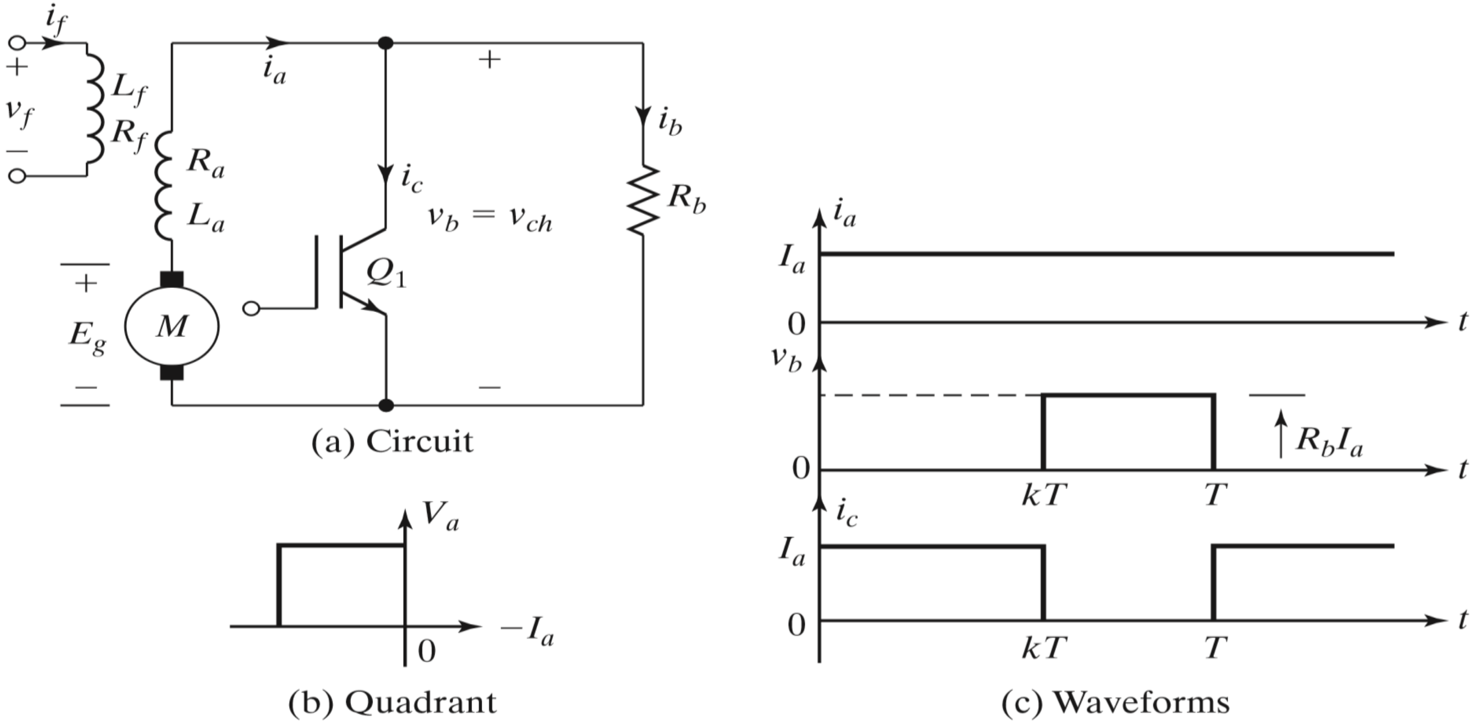
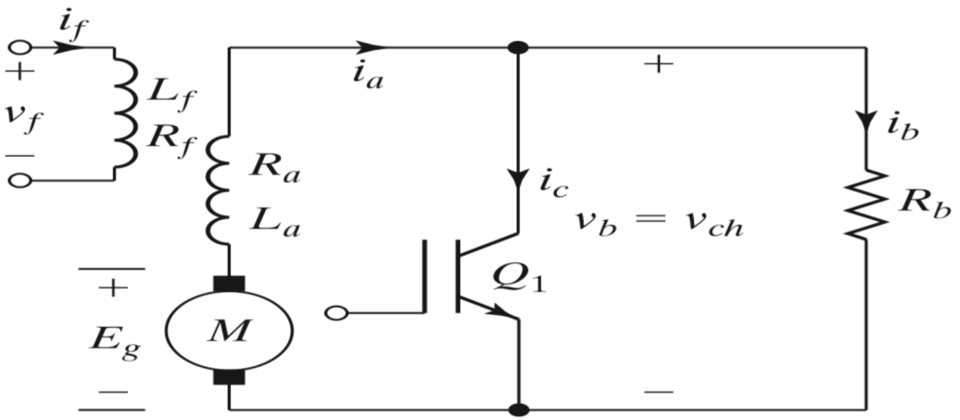


FIGURE 3

Rheostatic braking of dc separately excited motors.



assuming that the armature current continuous and free ripple

The average current of the braking resistor,

$$I_b = I_a(1 - k)$$

and the average voltage across the braking resistor,

$$V_b = R_b I_a(1 - k)$$

The equivalent load resistance of the generator,

$$R_{eq} = \frac{V_b}{I_a} = R_b(1 - k) + R_m$$

The power dissipated in the resistor R_b is

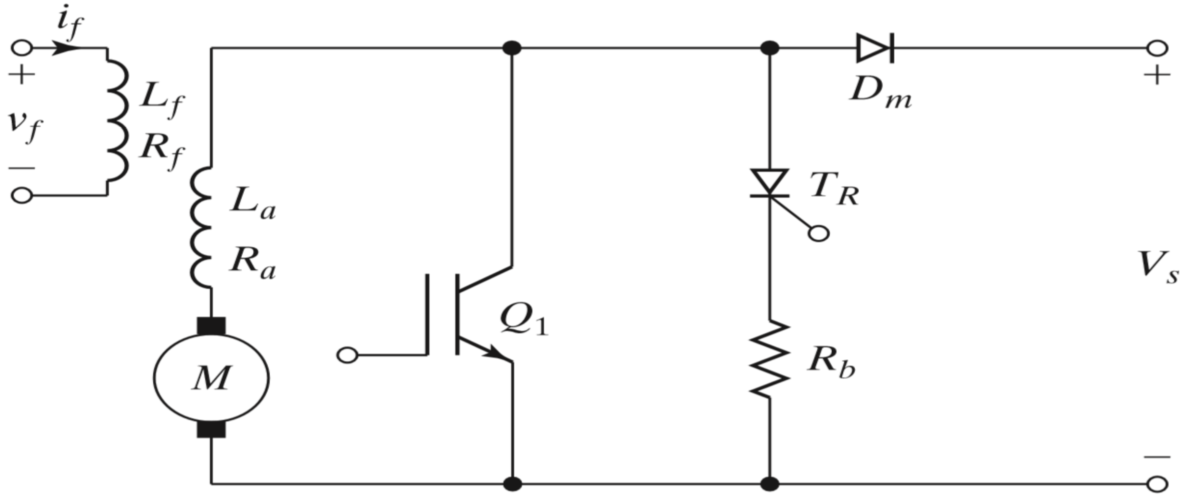
$$P_b = I_a^2 R_b(1 - k)$$

By controlling the duty cycle k, the effective load resistance can be varied from R_m to $R_m + R_b$, and the braking power can be controlled. The braking resistance R_b determines the maximum voltage rating of the dc–dc converter.

principle of Combined regenerative and rheostatic Brake Control

Regenerative braking is energy-efficient braking. On the other hand, the energy is dissipated as heat in rheostatic braking. If the supply is partly receptive, which is normally the case in practical traction systems, a combined regenerative and rheostatic brake control would be the most energy efficient. Fig. 4. shows an arrangement in which rheostatic braking is combined with regenerative braking.

During regenerative brakings, the line voltage is sensed continuously. If it exceeds a certain preset value, normally 20% above the line voltage, the regenerative braking is removed and a rheostatic braking is applied. It allows an almost instantaneous



Combined regenerative and rheostatic braking.

Two- and Four-Quadrant Dc–dc Converter Drives

During power control, a dc–dc converter-fed drive operates in the first quadrant, where the armature voltage and armature current are positive. In a regenerative braking, the dc–dc converter drive operates in the second quadrant, where the armature voltage is positive and the armature current is negative. Two-quadrant operation, as shown in Fig.4, is required to allow power and regenerative braking control.

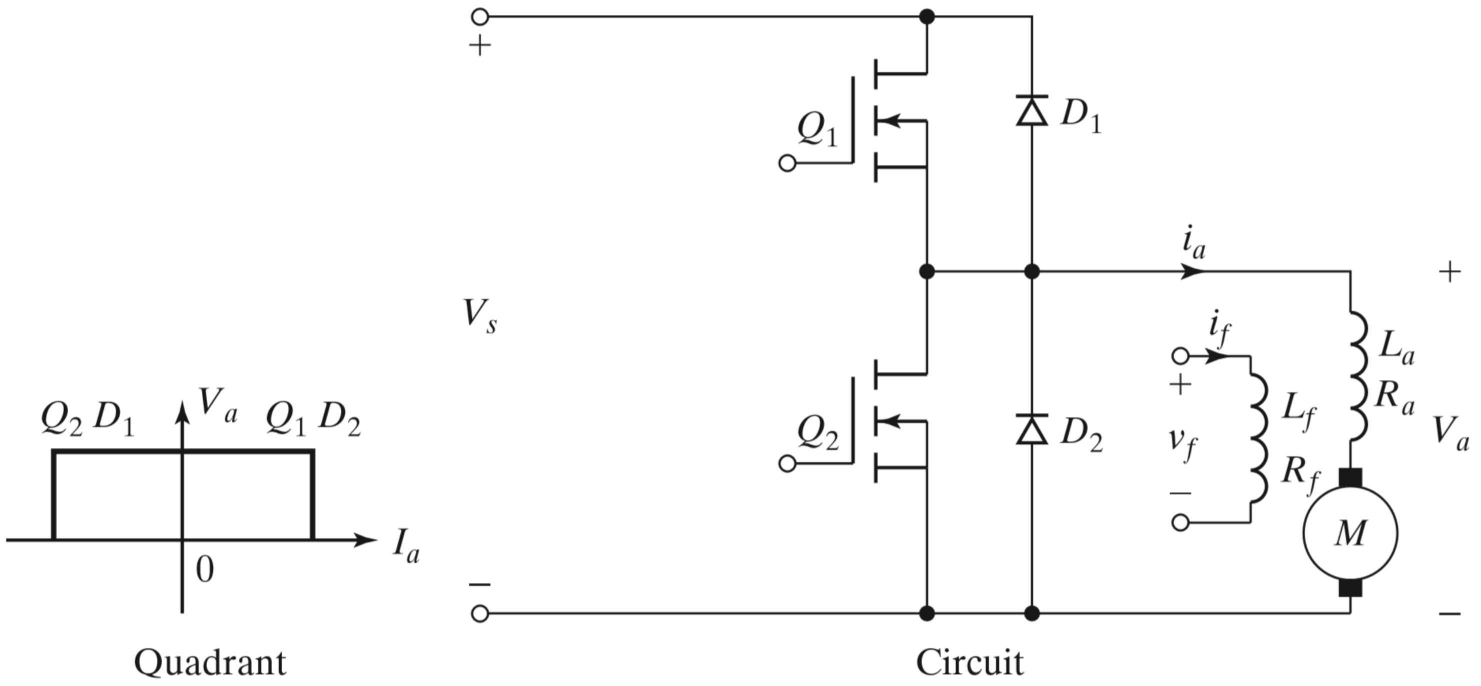


FIGURE4.

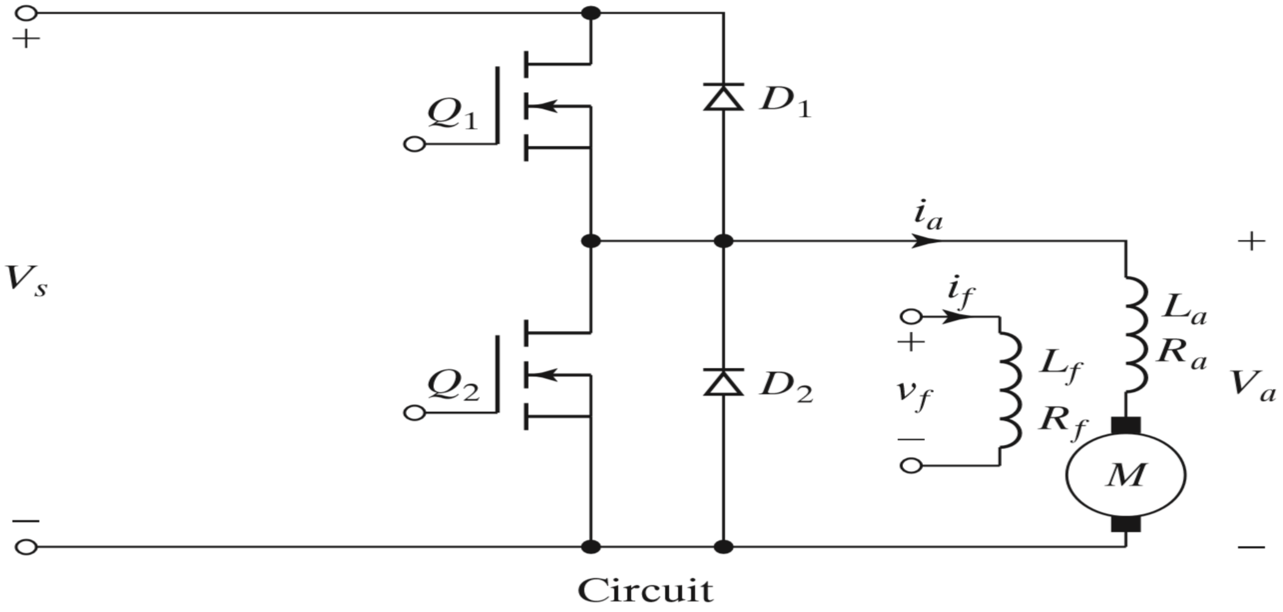


FIGURE4.

Power control. Transistor Q_1 and diode D_2 operate. When Q_1 is turned on, the supply voltage V_s is connected to the motor terminals. When Q_1 is turned off, the armature current that flows through the freewheeling diode D_2 decays.

Regenerative control. Transistor Q_2 and diode D_1 operate. When Q_2 is turned on, the motor acts as a generator and the armature current rises. When Q_2 is turned off, the motor, acting as a generator, returns energy to the supply through the regenerative diode D_1.

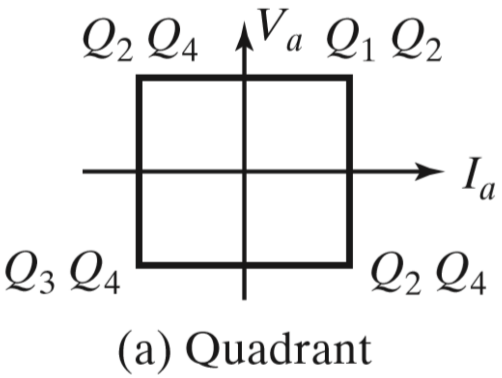


Figure 1b

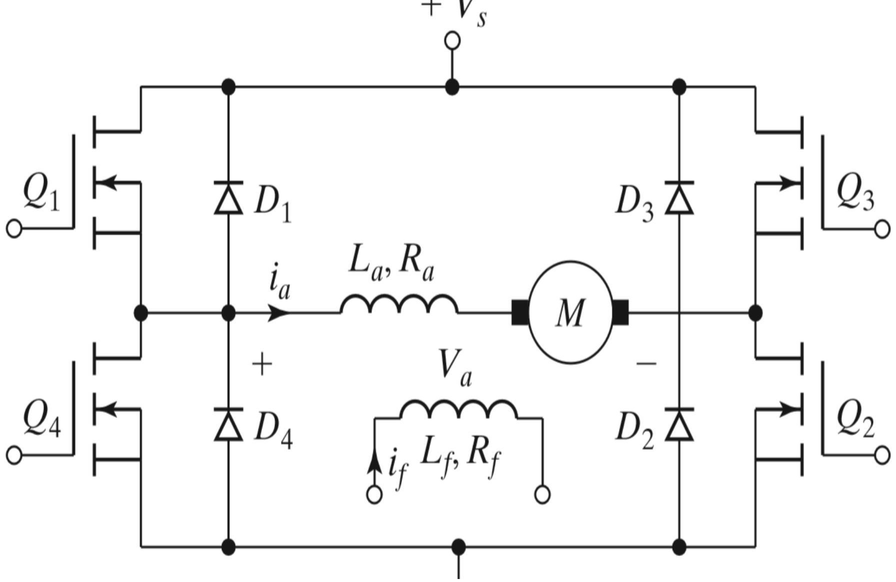


Figure 1a

In industrial applications, four-quadrant operation, as shown in Figure 1a, is required. A transistorized four-quadrant drive is shown in Figure 1b.

1- Forward power control. Transistors Q1 and Q2 operate. Transistors Q3 and Q4 are off. When Q1 and Q2 are turned on together, the supply voltage appears across the motor terminals and the armature current rises. When Q1 is turned off and Q2 is still turned on, the armature current decays through Q2 and D4. Alternatively, both Q1 and Q2 can be turned off, while the armature current is forced to decay through D3 and D4.

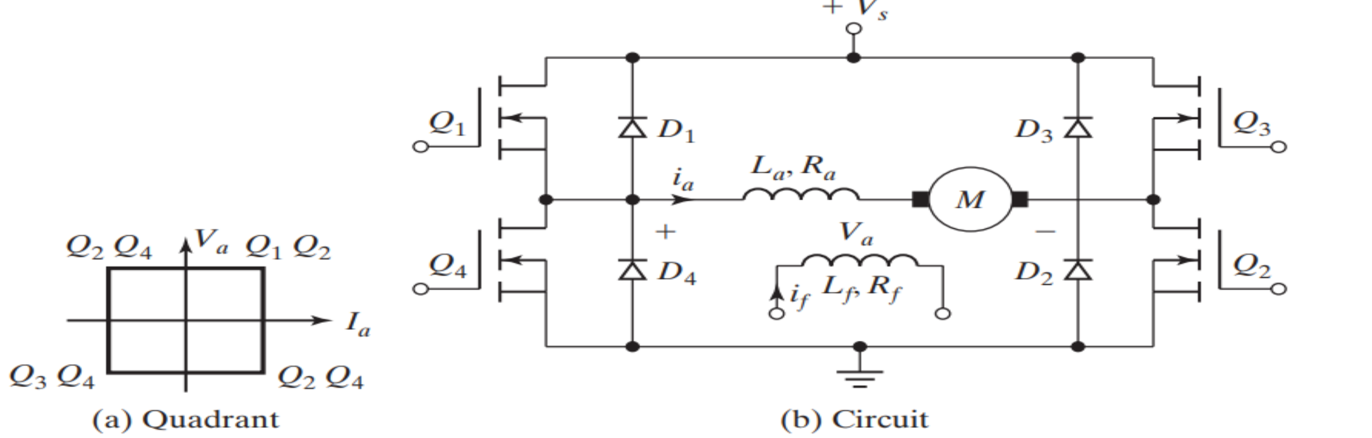


FIGURE 14.20

Four-quadrant transistorized dc—dc converter drive.

turned on, the armature current decays through Q_2 and D_4. Alternatively, both Q_1 and Q_2 can be turned off, while the armature current is forced to decay through D_3 and D_4.

Forward regeneration. Transistors Q_1, Q_2, and Q_3 are turned off. When transistor Q_4 is turned on, the armature current, which rises, flows through Q_4 and D_2. When Q_4 is turned off, the motor, acting as a generator, returns energy to the supply through D_1 and D_2.

Reverse power control. Transistors Q_3 and Q_4 operate. Transistors Q_1 and Q_2 are off. When Q_3 and Q_4 are turned on together, the armature current rises and flows in the reverse direction. When Q_3 is turned off and Q_4 is turned on, the armature current falls through Q_4 and D_2. Alternatively, both Q_3 and Q_4 can be turned off, while forcing the armature current to decay through D_1 and D_2.

Reverse regeneration. Transistors Q_1, Q_3, and Q_4 are off. When Q_2 is turned on, the armature current rises through Q_2 and D_4. When Q_2 is turned off, the armature current falls and the motor returns energy to the supply through D_3 and D_4.

Multilevel inverter

A simple topology for dc to ac converter is the half bridge rectifier given in Fig. (1). When S1 turns ON for time T/2 while S2 is OFF the instantaneous voltage across the load VAo, equal Vdc/2 to complete one cycle for a period T second, S2 is turned ON while S1 is OFF for a time T/2 the voltage V_{AO} will be –Vdc/2, to avoid short circuit on the supply S1, S2 are never turned ON at the same time. Fig. (2) shows the output voltage waveform of half bridge configuration.

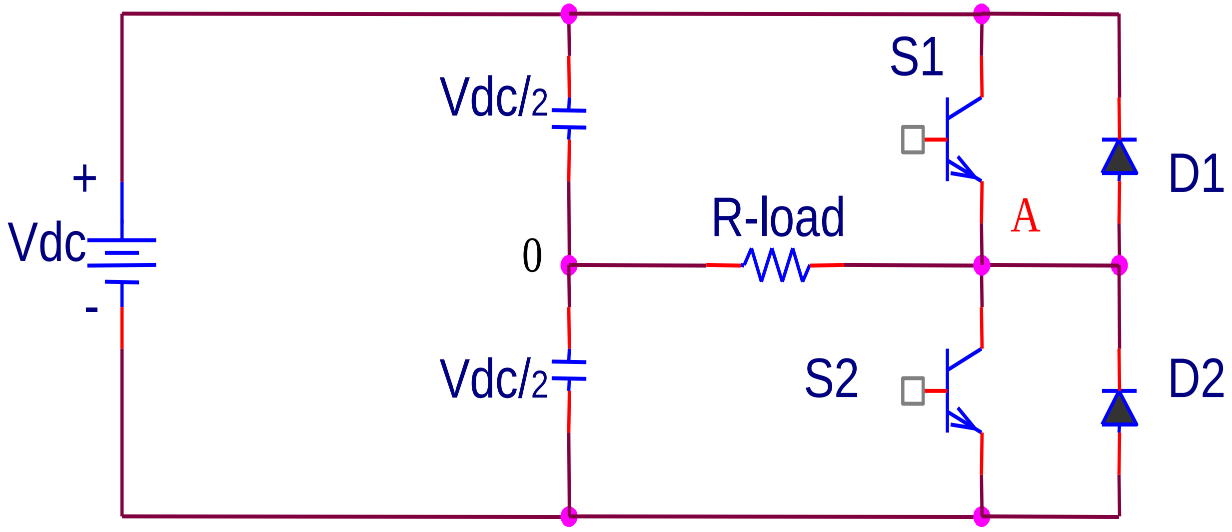


Fig. (1.) half bridge inverter configuration

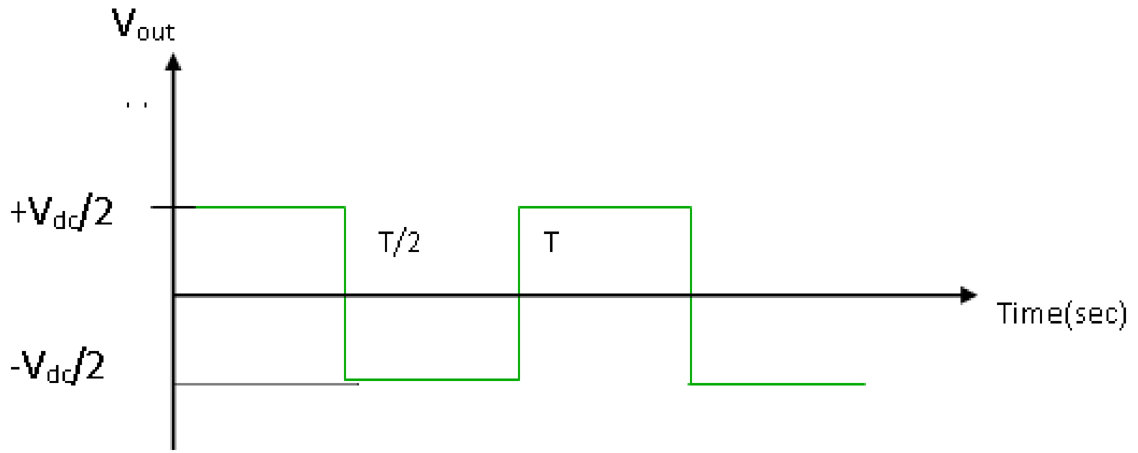


Fig. (2) output waveform of half bridge inverter configuration

In full bridge inverter shown in Fig. (3) S1, S2 are turned ON while S3, S4 are OFF the voltage V_{AO} equal V_{dc} and S1, S2 are turn OFF while S3, S4 are turned ON and the voltage V_{AO} equals $-V_{dc}$, To get zero voltage S1,S3 are turned ON while S2 and S4 are OFF or vice versa, to avoid short circuit S1, S4 should not be closed at the same time, nor should S2, S3. Fig.(4) shows the output waveform of 3-level inverter.

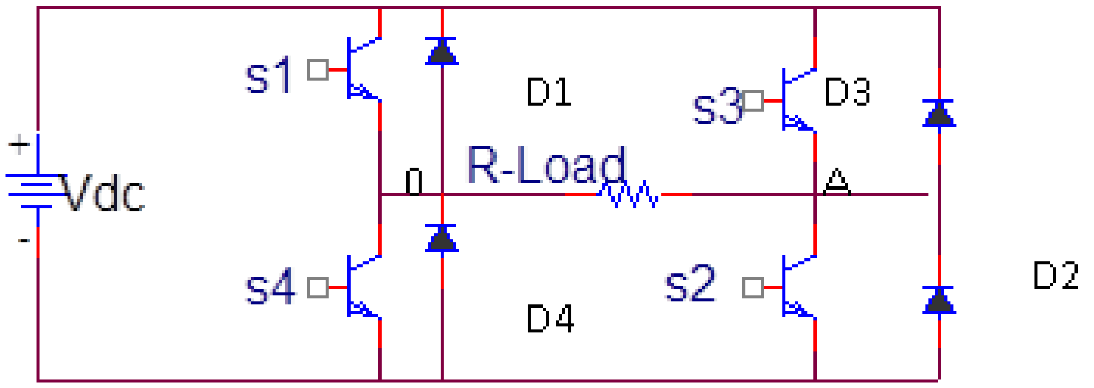


Fig. (3) full bridge inverter configuration

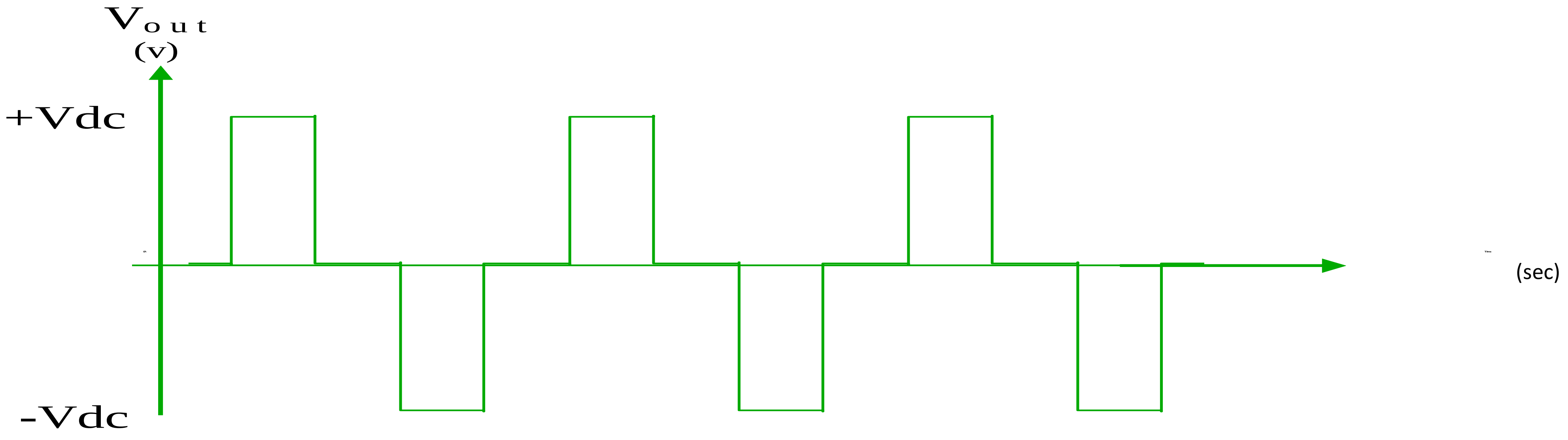


Fig. (4) full bridge inverter configuration