Dr. Norbert Cheung's Series in Electrical Engineering

Level 5 Topic no: 7

Power Drives

Contents

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1. Four Quadrant Drive of DC Motor

We can readily achieve 4-quadrant control of a dc machine by using a single converter, combined with either field or armature reversal. However, a great deal of switching may be required.

Four-quadrant control is possible without field or armature reversal by using two converters operating back-to-back. They may function either alternately or simultaneously, as previously described.

Example

An industrial drive has to develop the torque-speed characteristic given in Fig. 4-9. A dc shunt motor is used, powered by two converters operating back-to-back.

The converters function alternately (only one at a time). Determine the state of each converter over the 26-second operating period, and indicate the polarity at the terminals of the dc machine.

The speed and torque are considered positive when acting clockwise.

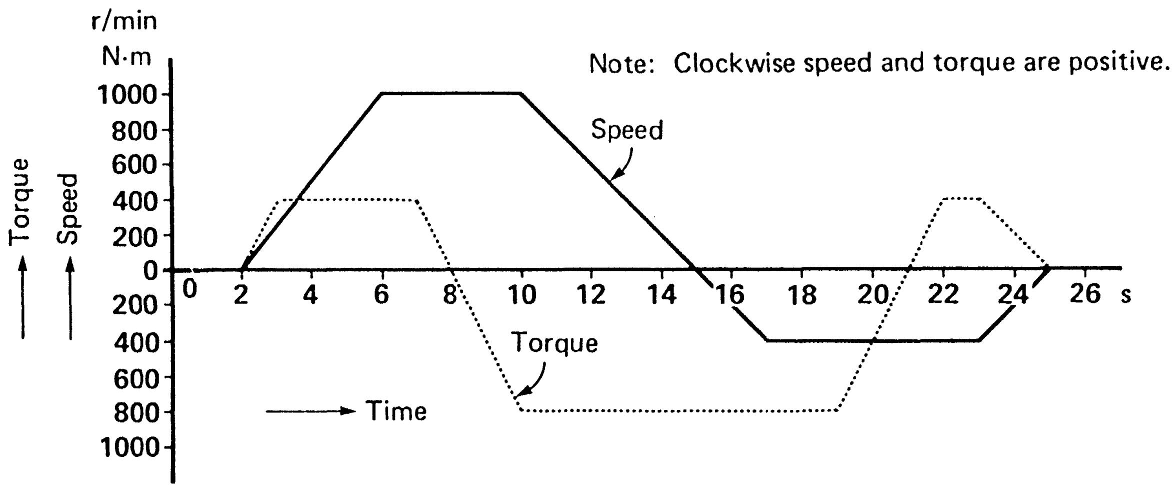
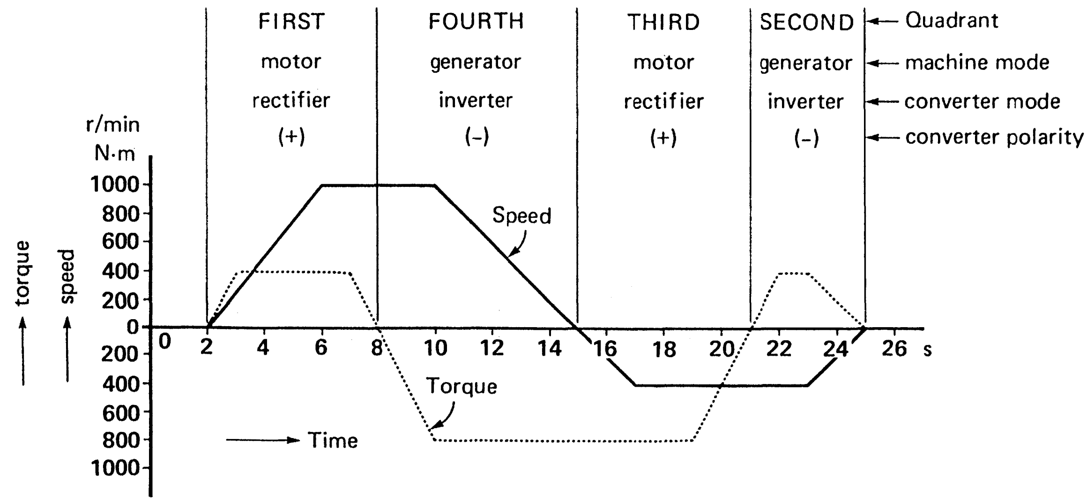


Figure 4-9 Torque-speed characteristic of an industrial drive.



The analysis of such a drive is simplified by subdividing the torque-speed curve into the respective 4 quadrants.

In doing so, we look for those moments when either the torque or speed pass through zero. These moments always coincide with the transition from one quadrant to another.

Referring to Fig., the speed or torque passes through zero at 2, 8, 15, 21, and 25s.

We draw vertical lines through these points. We then examine whether the torque and speed are positive or negative during each interval. Knowing the respective signs, we can immediately state in which quadrant the motor is operating. For example, during the interval from 2 s to 8 s, both the torque and speed are positive. Consequently, the machine is operating in quadrant 1. On the other hand, in the interval from 21 s to 25 s, the speed is negative and the torque positive, indicating operation in quadrant 2.

Knowing the quadrant, we know whether the machine functions as a motor or generator. Finally, assuming that a positive (clockwise) speed corresponds to a "positive" armature voltage, we can deduce the required direction of current flow.

Time interval	Operating mode	
	converter 1	converter 2
2 - 8 s	rectifier	off
8 - 15 s	off	inverter
15 - 21 s	off	rectifier
21 - 25 s	inverter	off

Single-phase brush type DC drives

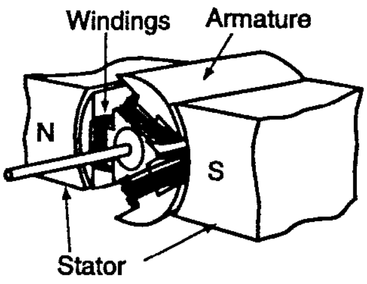


Figure 11.1 *A simple d.c. motor*

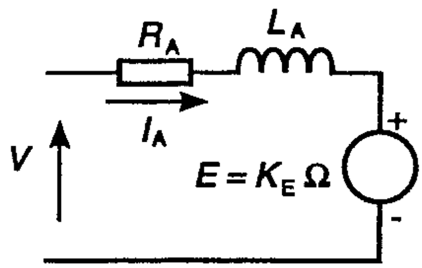
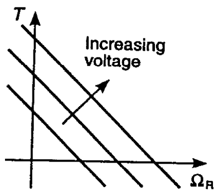


Figure 11.2 *A circuit model for a d.c. motor*



The torque against speed characteristics of a d.c. motor

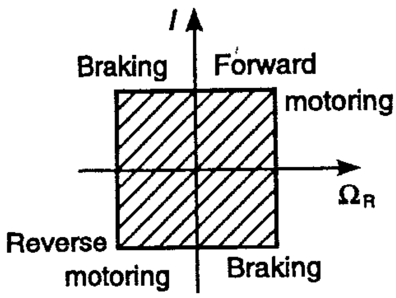


Figure 11.4 *The operating modes for a d.c. motor*

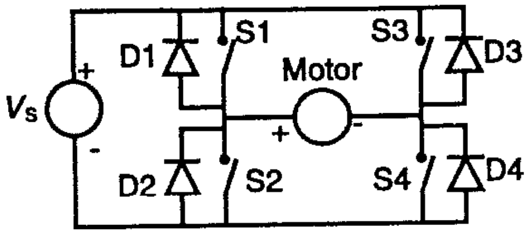


Figure 11.5 *A bridge driver circuit for a d.c. motor*

Current regulation, during motoring and braking

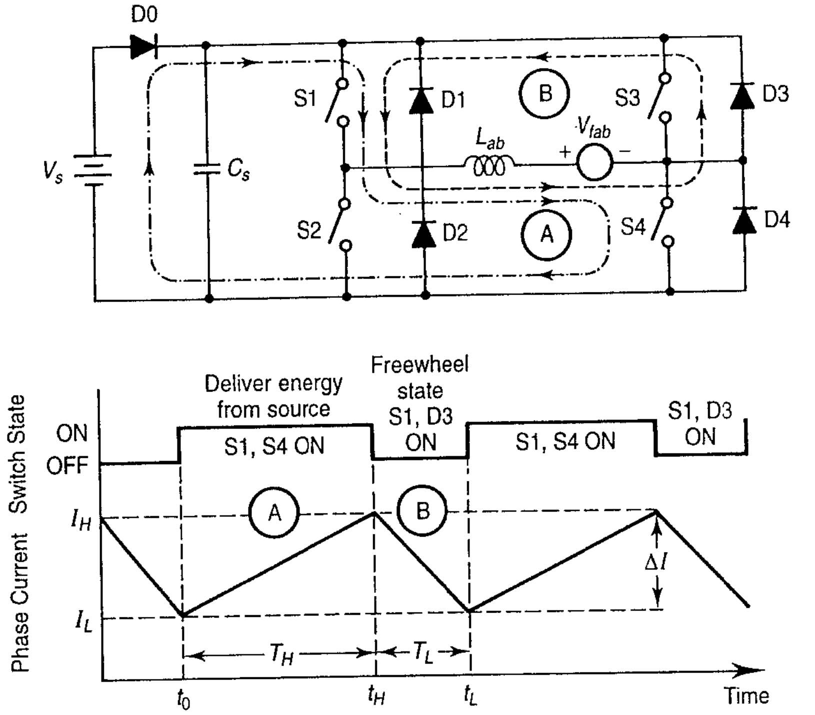


Figure 6-15. PWM current regulation in a trapezoidal PMAC machine during motoring operation, showing simplified drive equivalent circuit and associated steady-state waveforms.

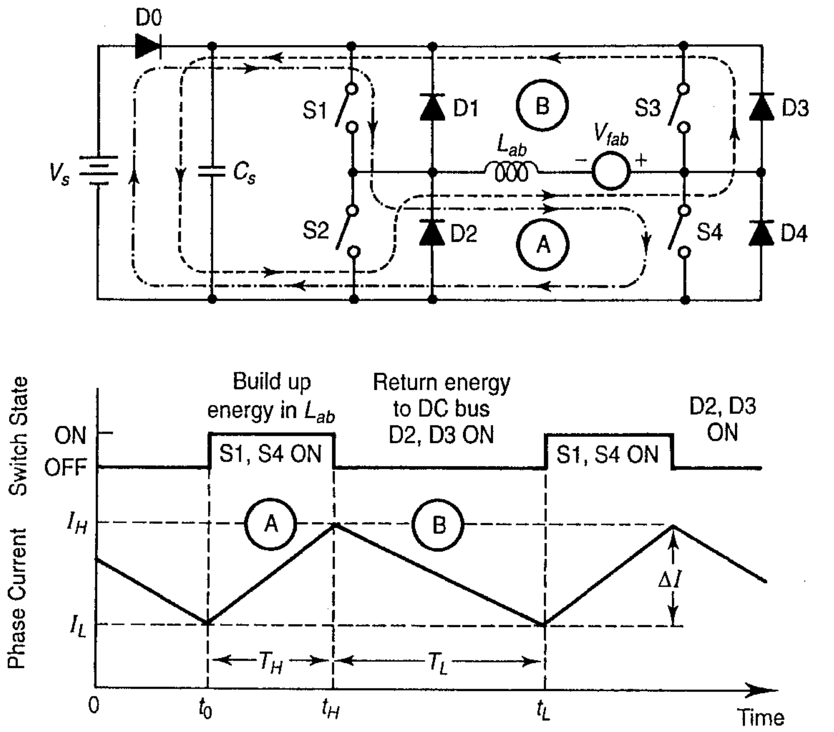


Figure 6-17. PWM current regulation in a trapezoidal PMAC machine during regenerative operation, showing simplified drive equivalent circuit and associated steady-state waveforms.

2. Convertor Configurations

Classification of Power Converters

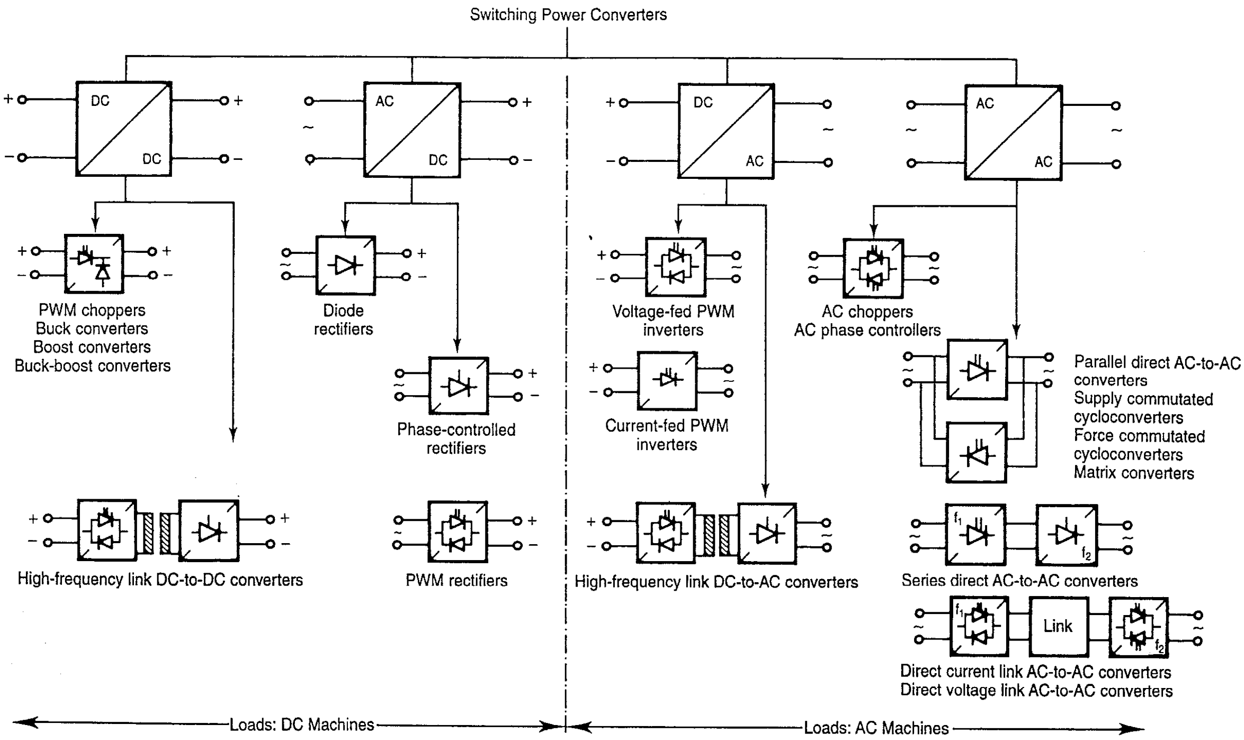
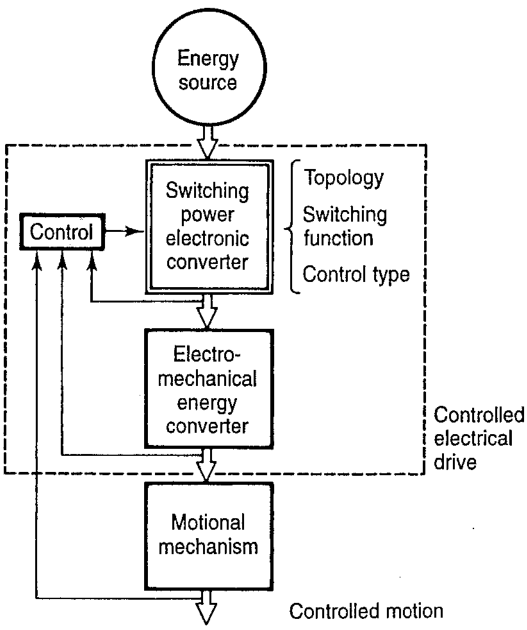
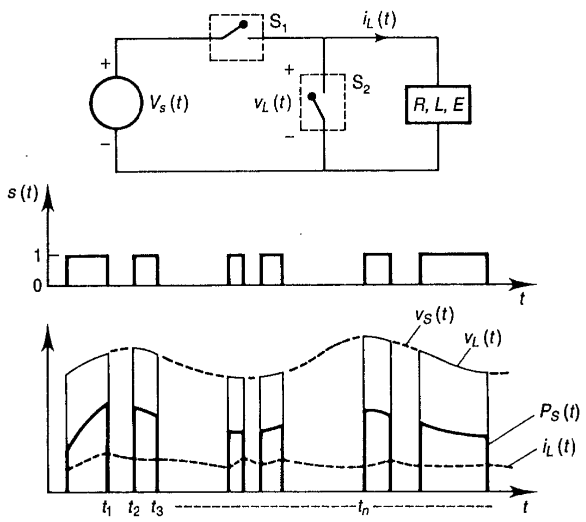


Figure 3-1. Functional classification of switching converter topologies and structures according to field of application.

Using power converters in drive systems



Controlling average energy flow in an inductive load by switching



Definition for circuit elements and topology structure

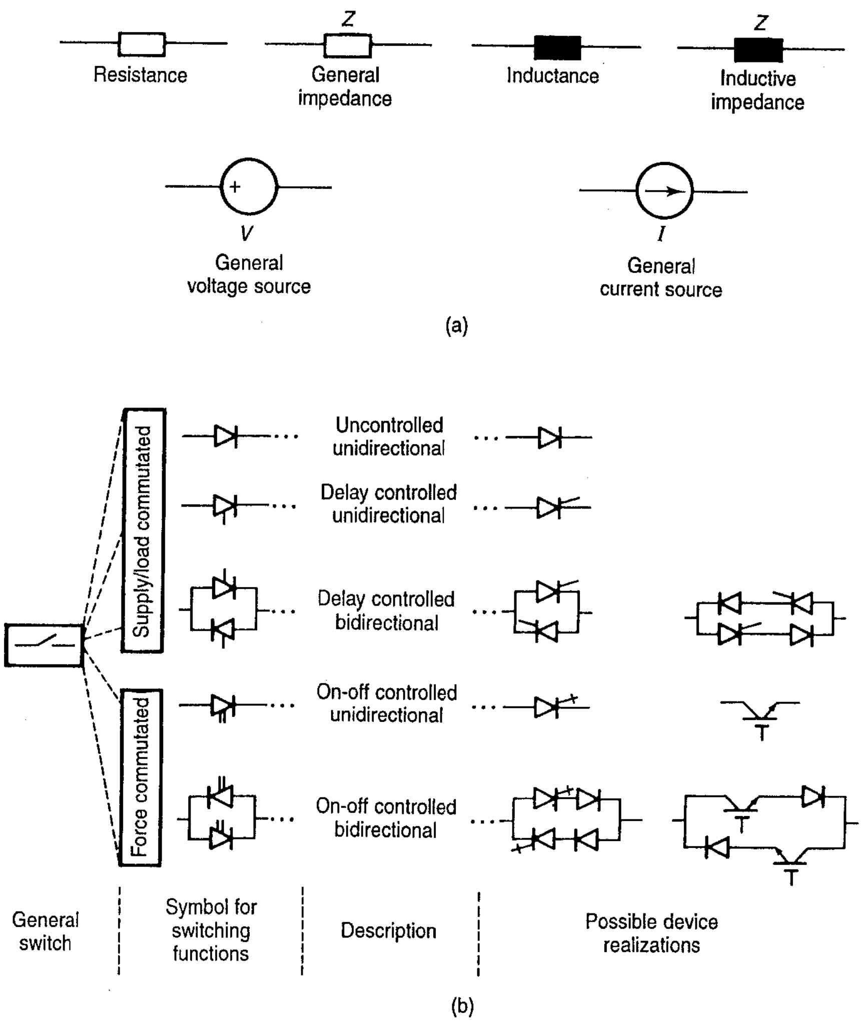


Figure 3-5. (a) Definitions for circuit elements; (b) symbols for different realisable switching functions.

Circuit elements and switching functions

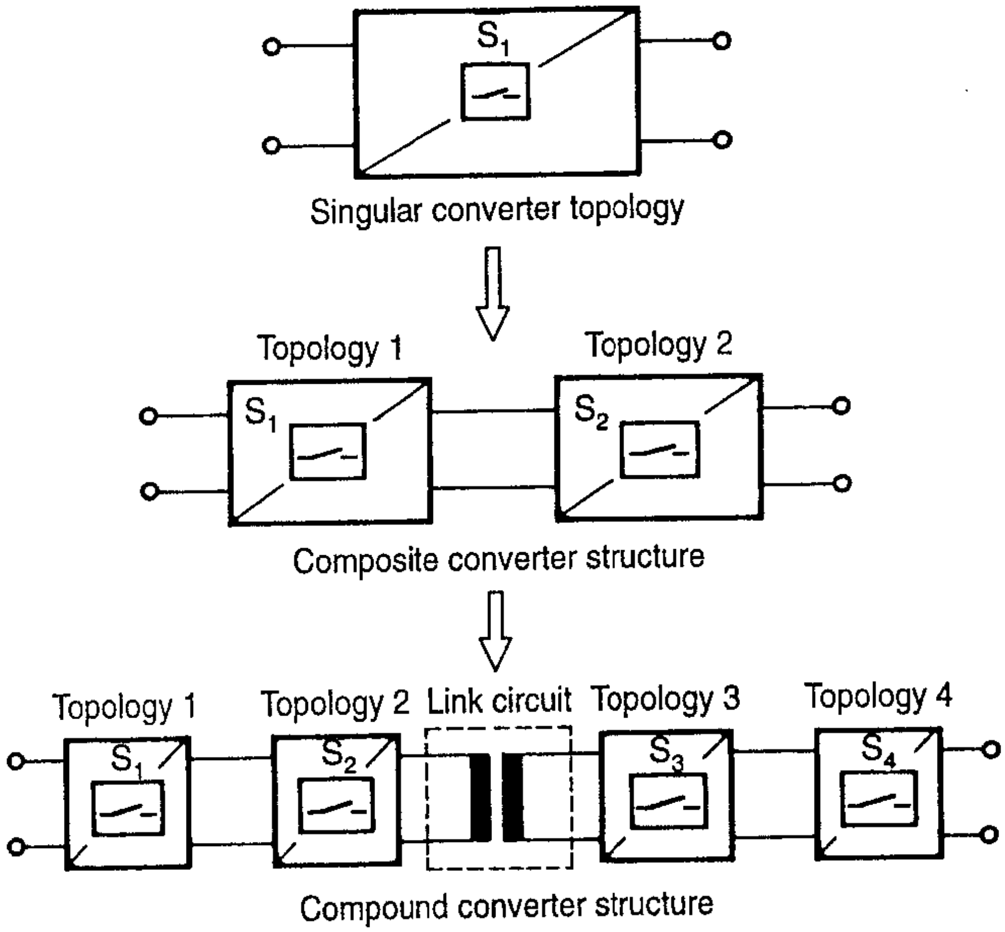


Figure 3-6. Illustrating topology and structure for singular, composite, and compound converters.

Topology structures - Converter topologies for single-phase motor drives

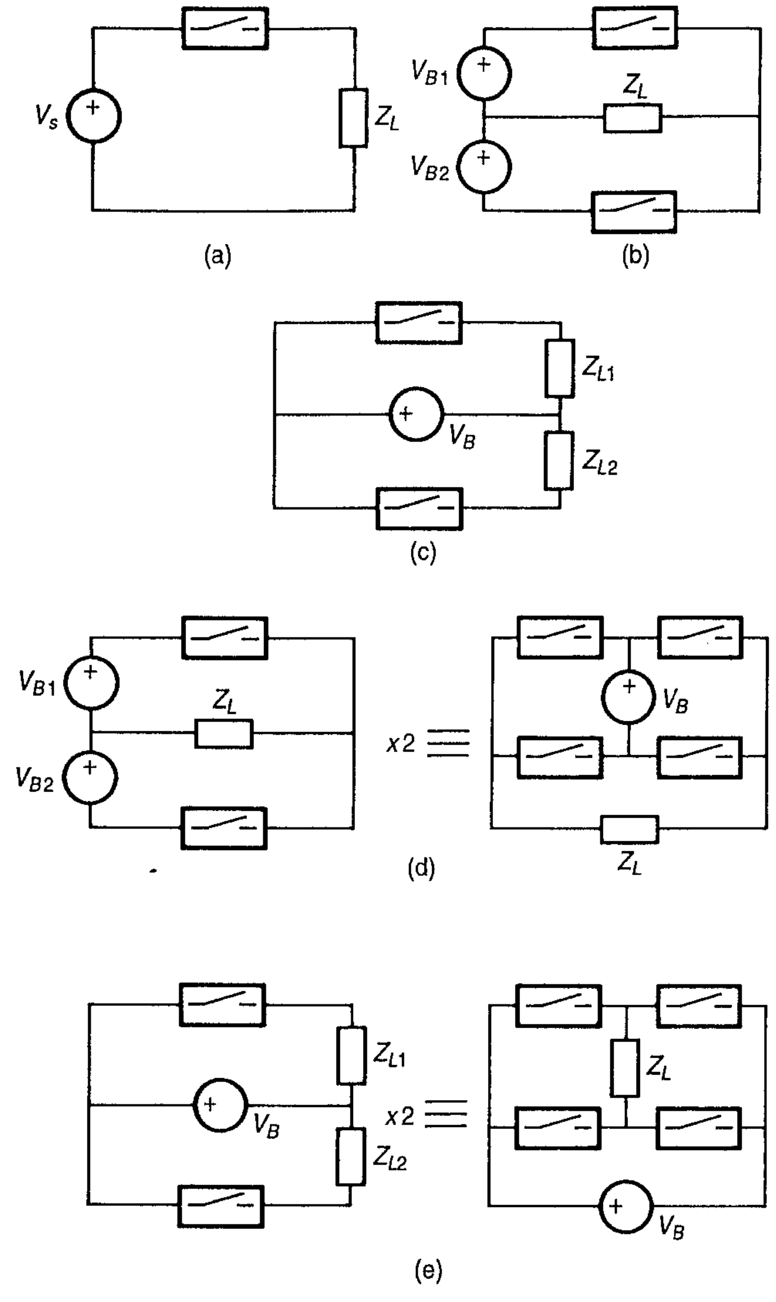


Figure 3-7. Evolution of the simplest bridge converter: (a) simple single-switch singular converter; (b) split-source double converter; (c) split-load double converter; (d) combination of two split-source converters into a bridge converter with source in the bridge; (e) combination of two split-load converters into a bridge converter with load in the bridge.

Converter topologies for multi-phase motor drives and supplies

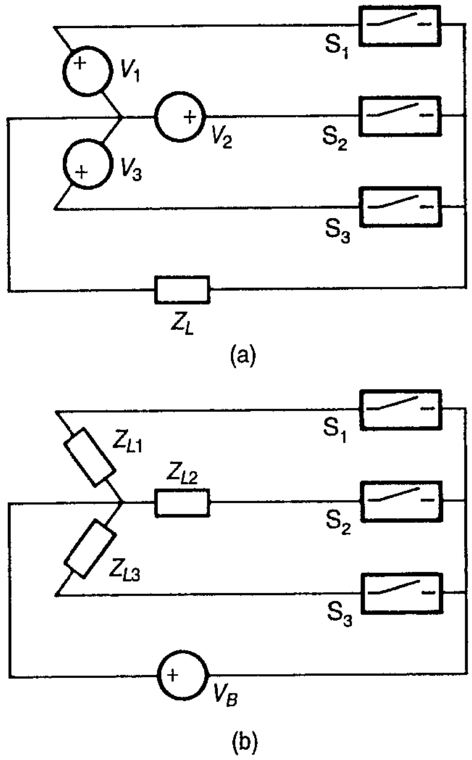


Figure 3-8. Multiphase topologies generated from the simple singular converter of Figure 3-7: (a) triple source combination of simple singular converter; (b) triple load combination of simple singular converter.

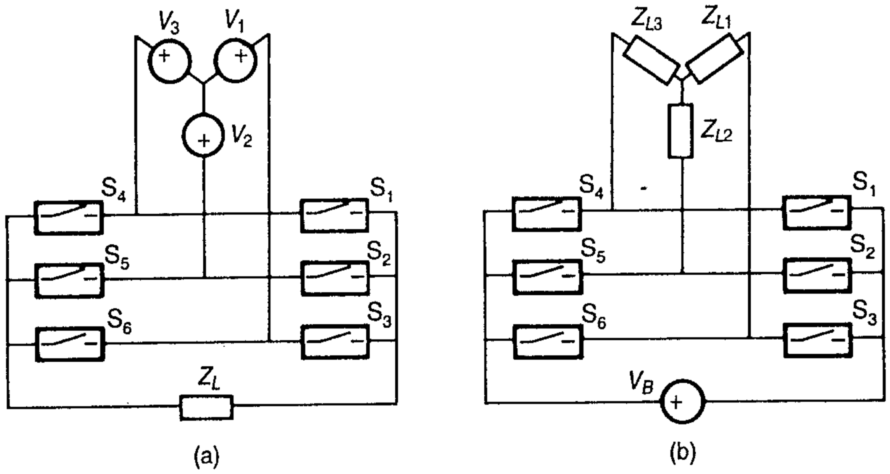


Figure 3-9. Generation of multiphase topologies: (a) combination of two of the converters of Figure 3-8a into a three-phase bridge; (b) combination of two of the converters of Figure 3-8b into a three-phase bridge.

Structures of Switching Converters

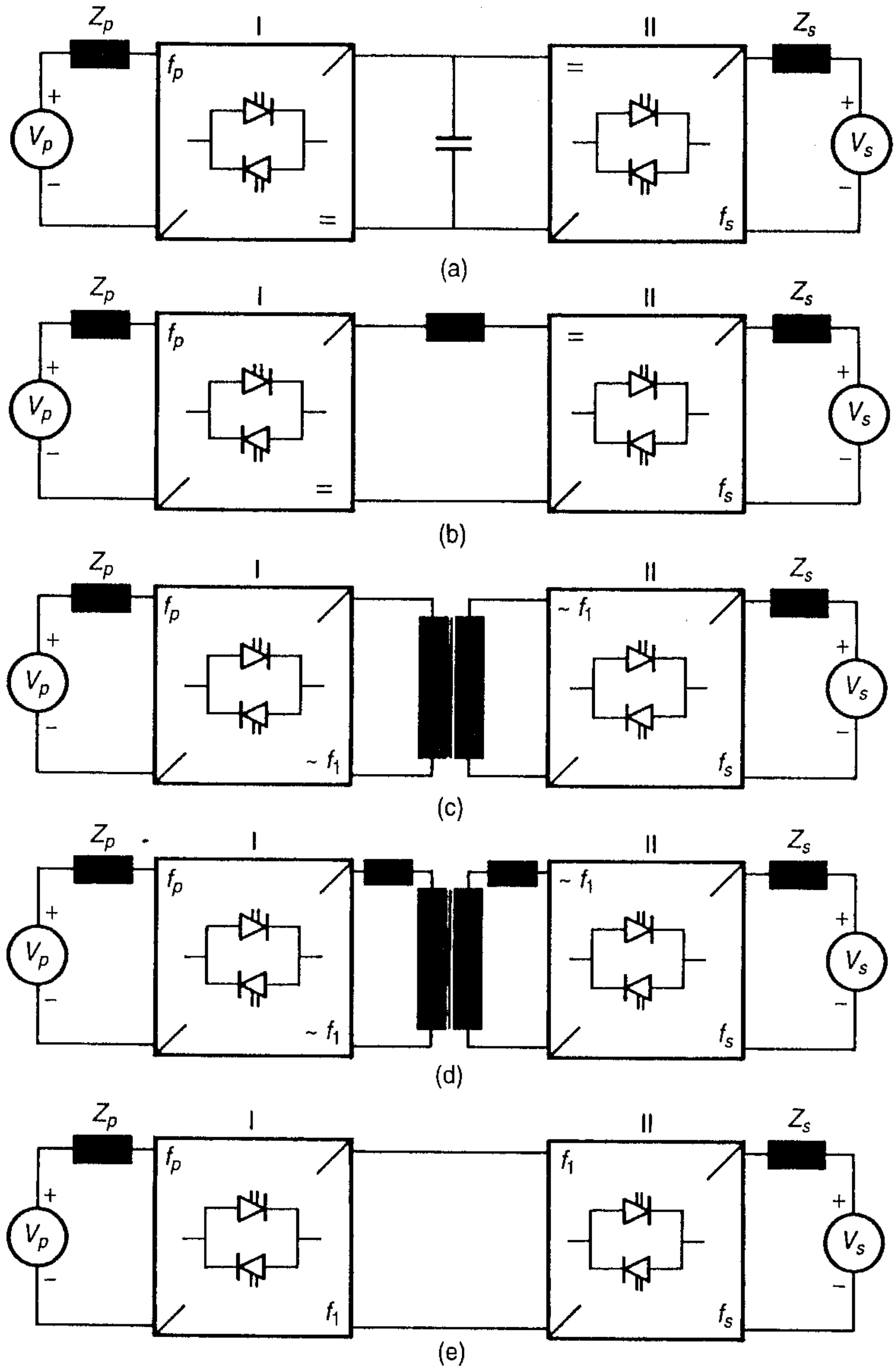


Figure 3-12. Structure of composite switching converters: (a) direct voltage link converter; (b) direct current link converter; (c) alternating voltage link converter; (d) alternating current link converter; (e) directly linked composite converter.

Multi-phase current-fed and voltage-fed converters

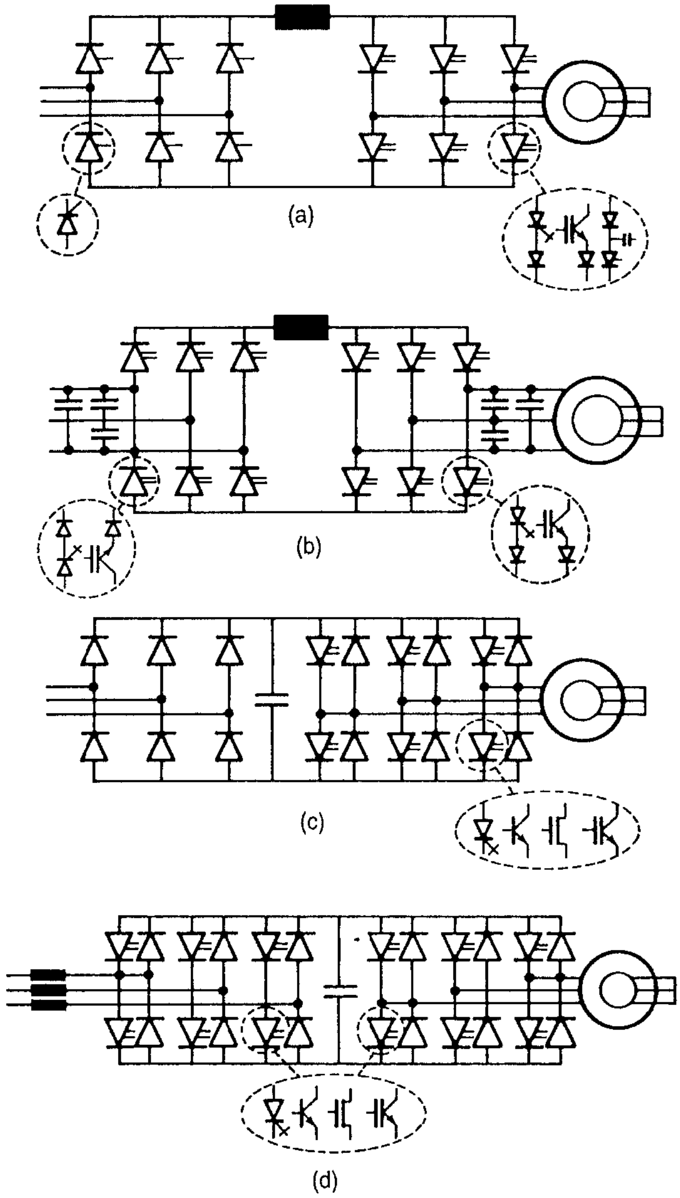


Figure 3-19. Composite AC-DC-AC converters: (a) current-fed inverter fed by a controlled three-phase rectifier; (b) current-fed PWM inverter fed by a current mode PWM rectifier; (c) voltage-fed PWM inverter fed by a three-phase diode rectifier; (d) voltage-fed PWM inverter fed by a three-phase PWM rectifier.

Important technologies in converter applications

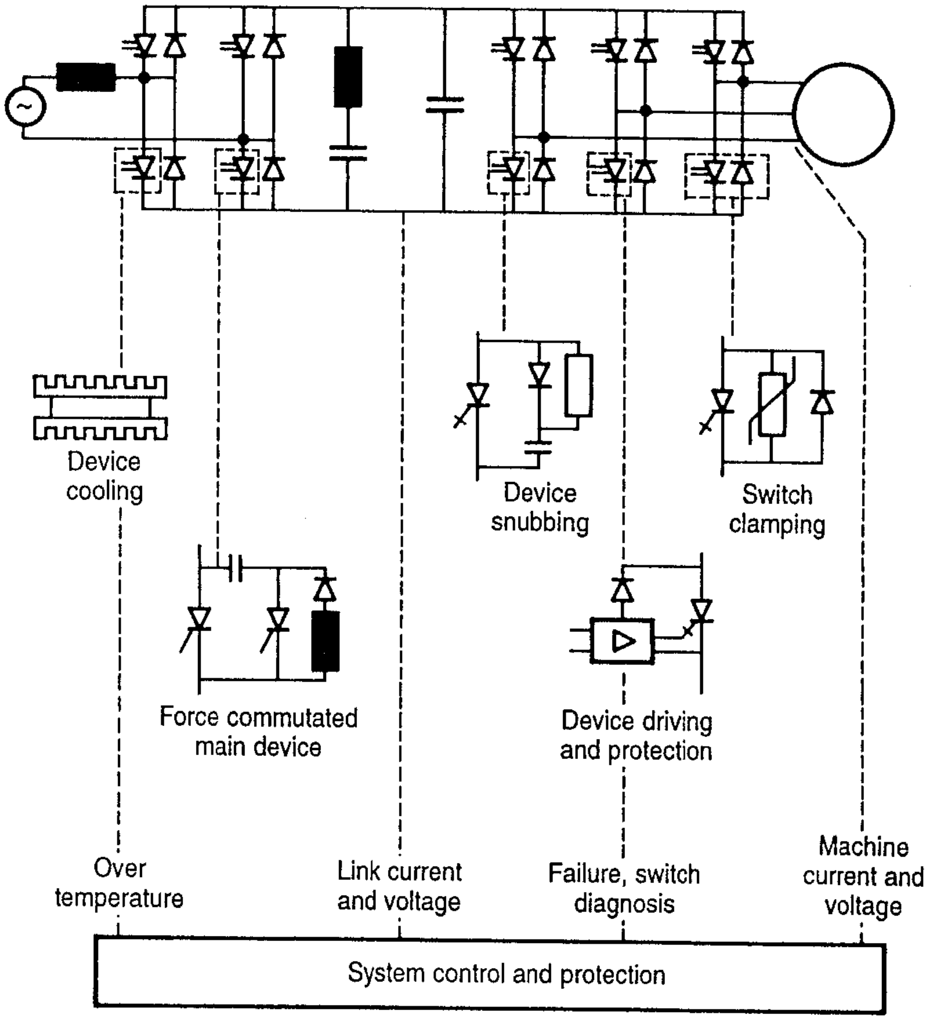
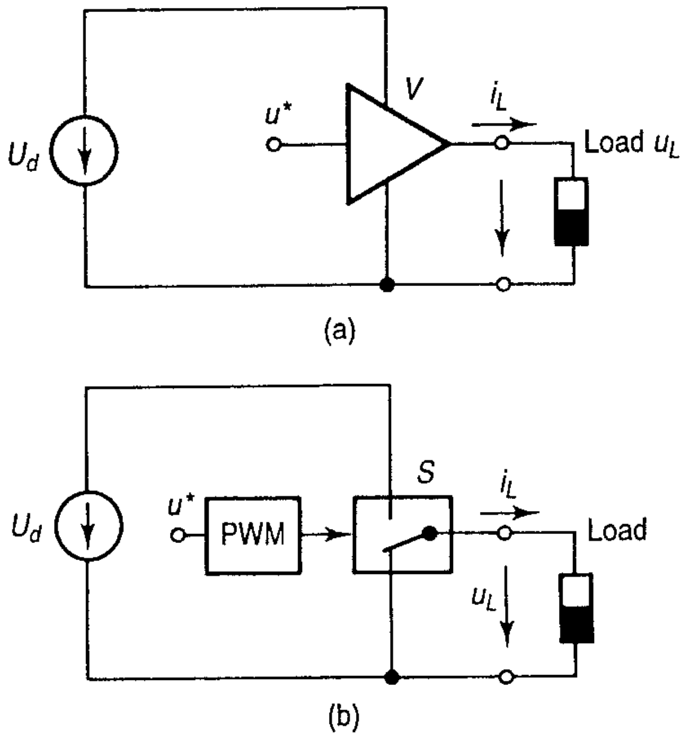
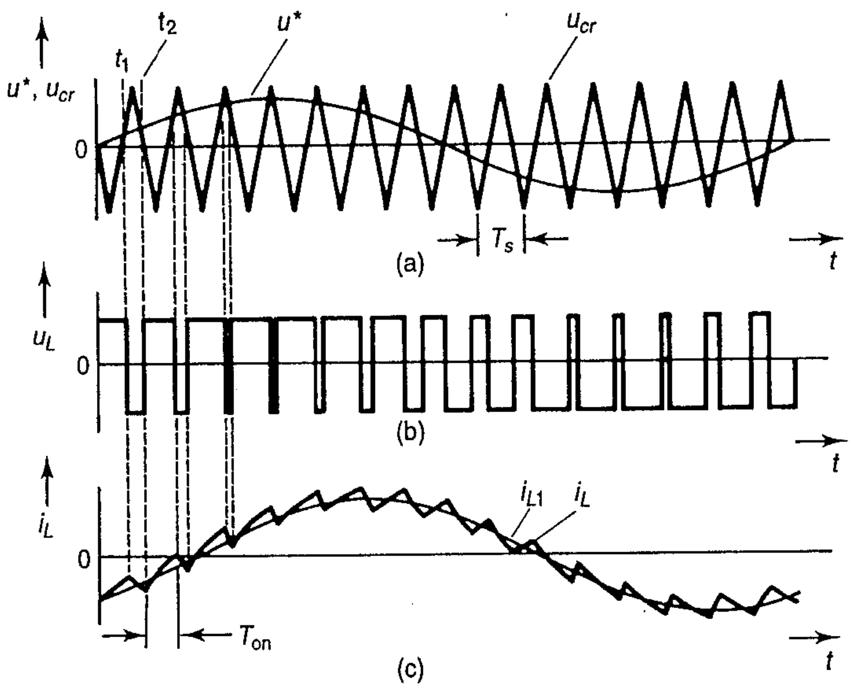


Figure 3-23. Important technologies in converter applications, illustrated by a motion control example on an AC-fed main line locomotive.

3. Pulse Width Modulation





Waveforms at pulse width modulation: (a) reference signal and carrier signal; (b) load voltage; (c) load current. The waveforms refer to the topology in Figure 4-5.

Comparison of semiconductor switches

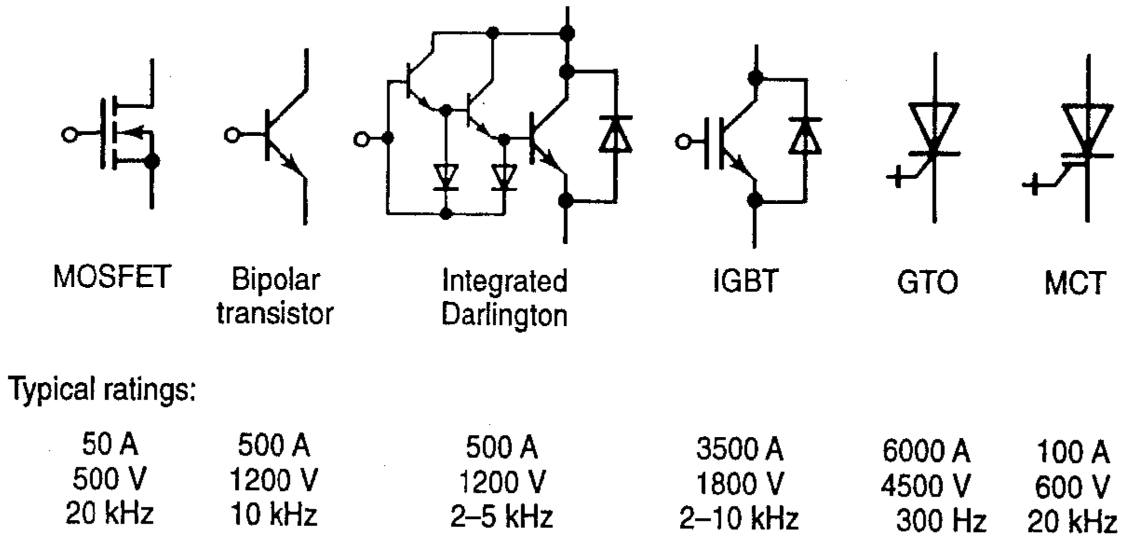
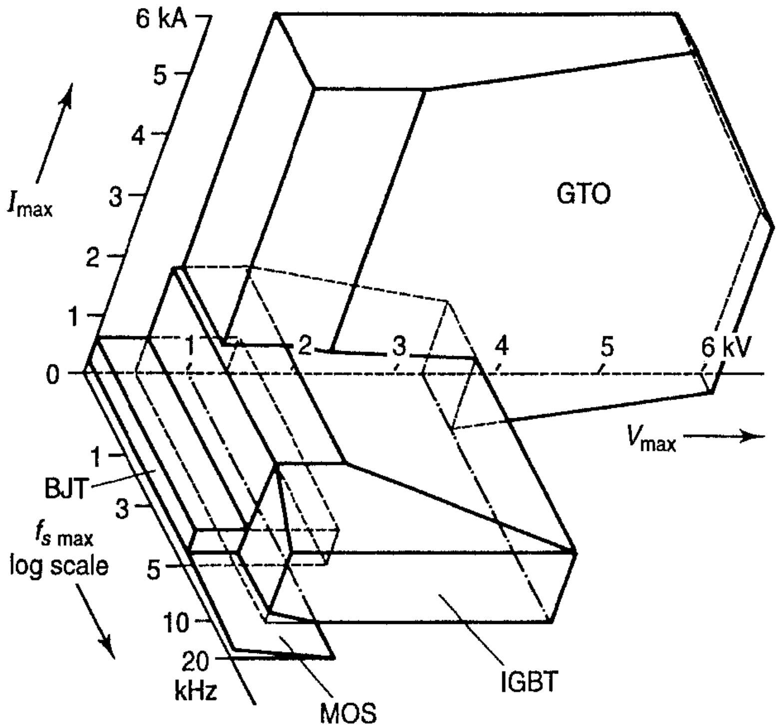
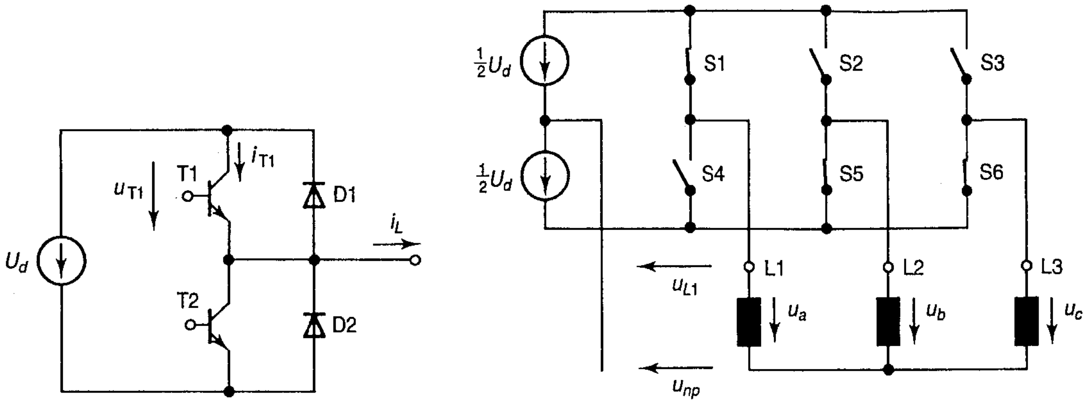


Figure 4-3. Power semiconductor switches and ratings.

MOS field effect transistor, transistor, darlington transistor, insulated gate bipolar transistor, gate turn-off thyristor, and MOS controlled thyristor



Single phase and three phase PWM switch pairs



Switch topologies

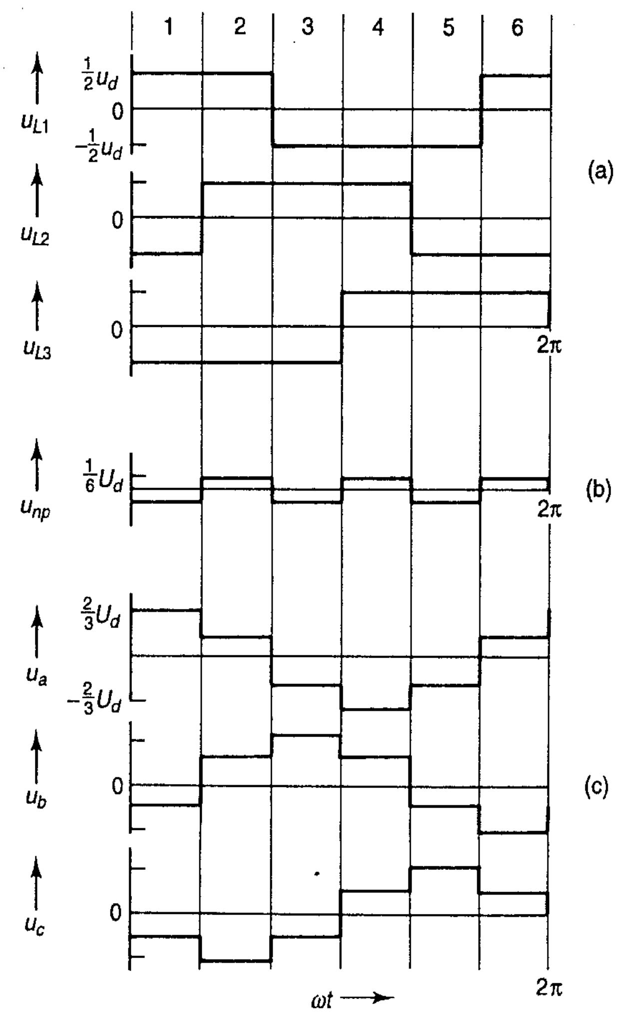


Figure 4-7. Switched three-phase waveforms: (a) voltage potentials at the inverter terminals; (b) neutral point potential at the load; (c) phase voltages of the load.

The three phase waveforms

Open loop and closed loop feedback PWM schemes

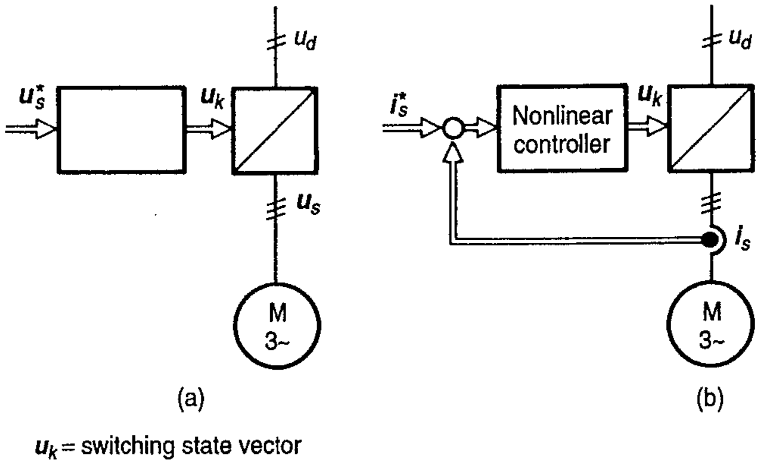


Figure 4-12. Basic PWM structures: (a) open loop scheme; (b) feedback scheme.

Open loop scheme - carrier based PWM scheme

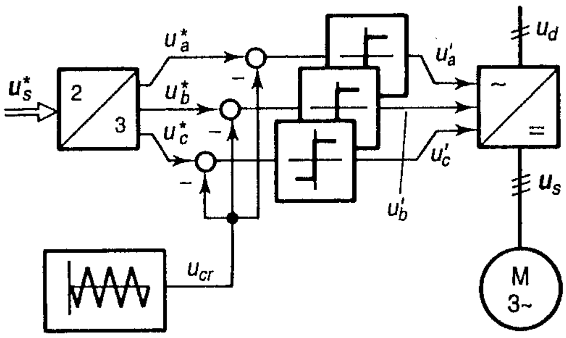


Figure 4-13. Suboscillation method, signal flow diagram.

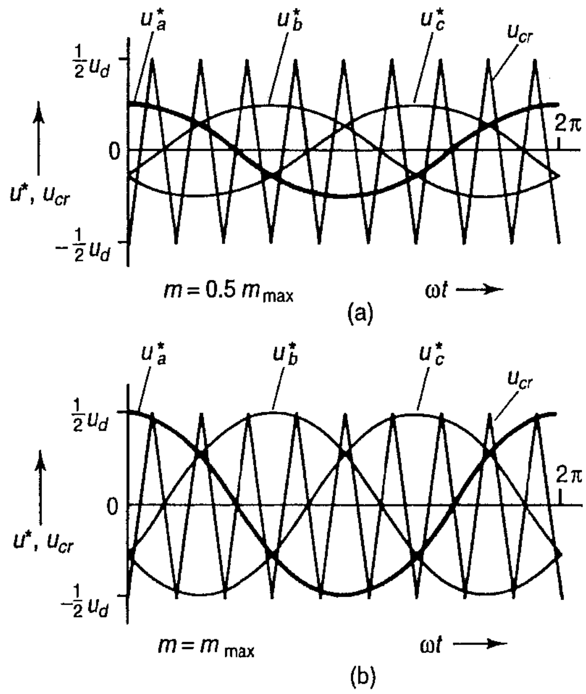


Figure 4-14. Reference signals and carrier signal: modulation index (a) $m = 0.5\, m_{\max}$, (b) $m = m_{\max}$.

Closed PWM control - hysteresis current control

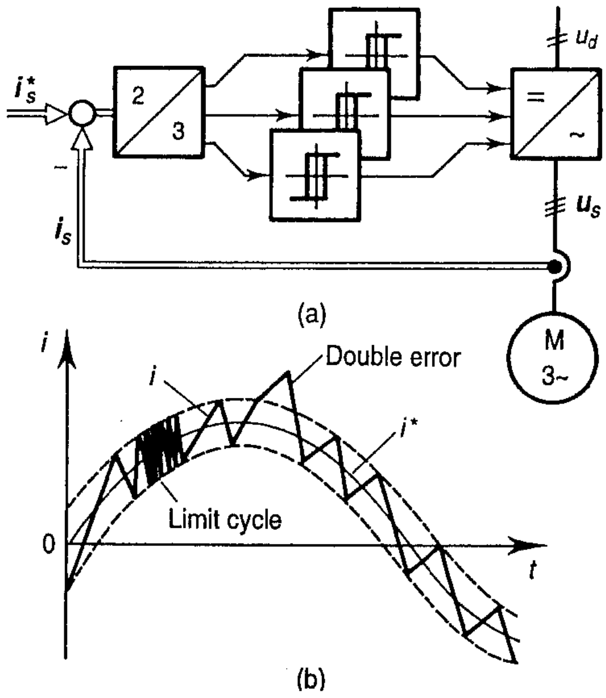


Figure 4-45. Hysteresis current control: (a) signal flow diagram; (b) basic current waveform.

Multi-level Converters

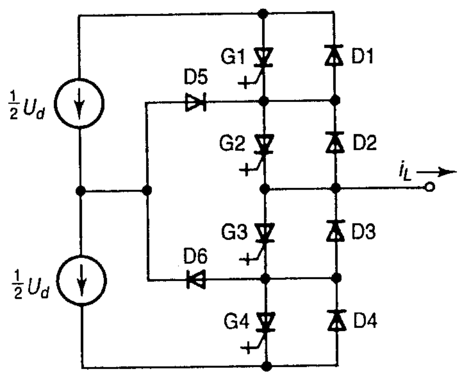


Figure 4-63. Inverter leg of a three-level topology

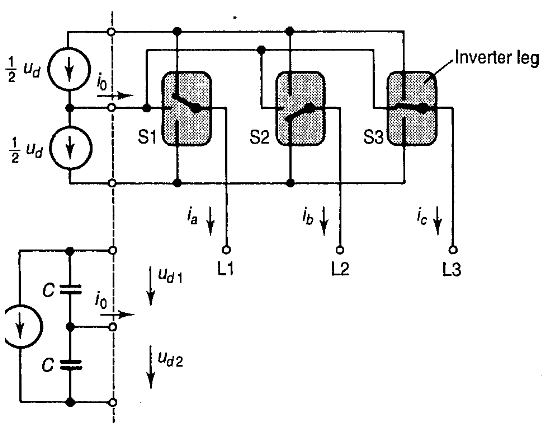


Figure 4-64. Three-level six-pulse bridge, schematic representation; lower portion: supply from a single DC source.

Multi-level converters waveforms

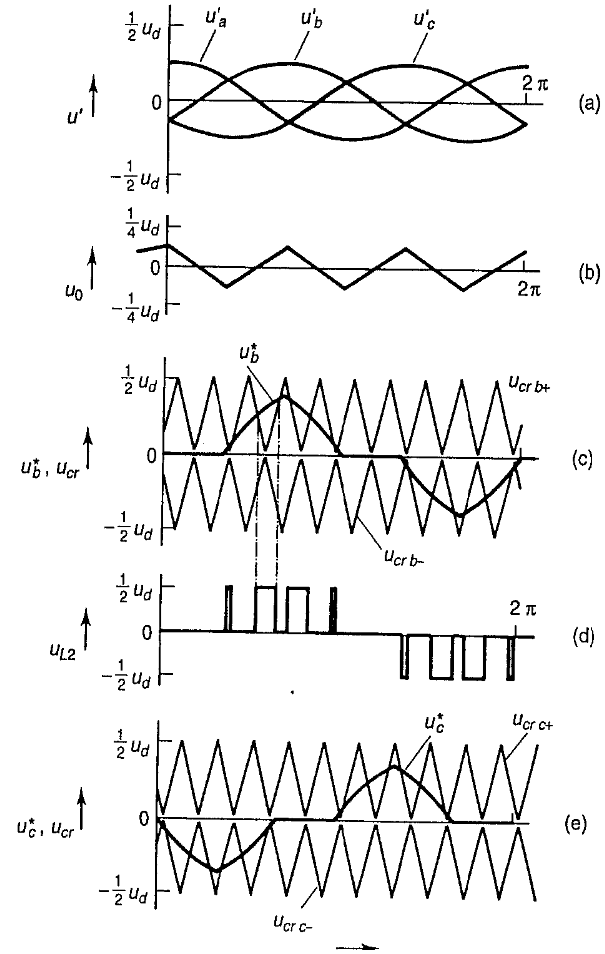


Figure 4-68. Three-level suboscillation method, $N = 4$: (a) sinusoidal three-phase signals; (b) zero-sequence signal, (c) reference signals and carrier signals, phase b; (d) phase potential u_{L2}; (e) reference signals and carrier signals, phase c.

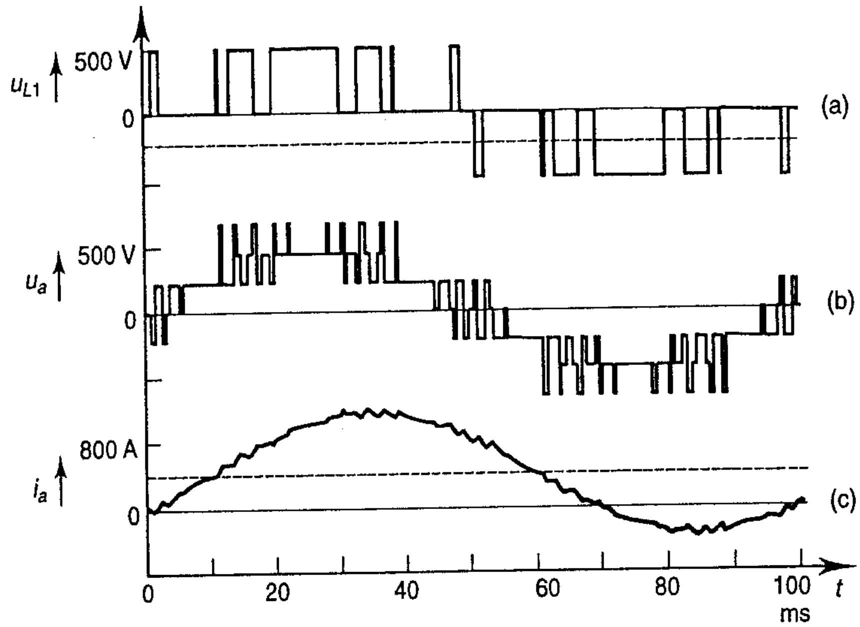
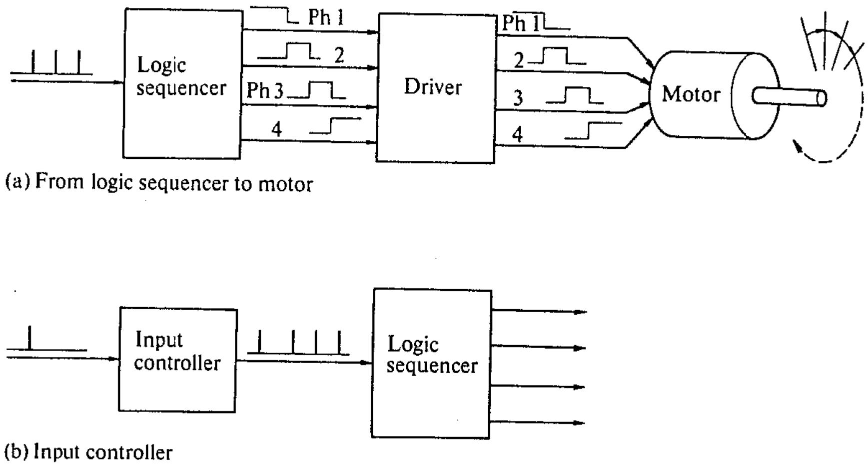


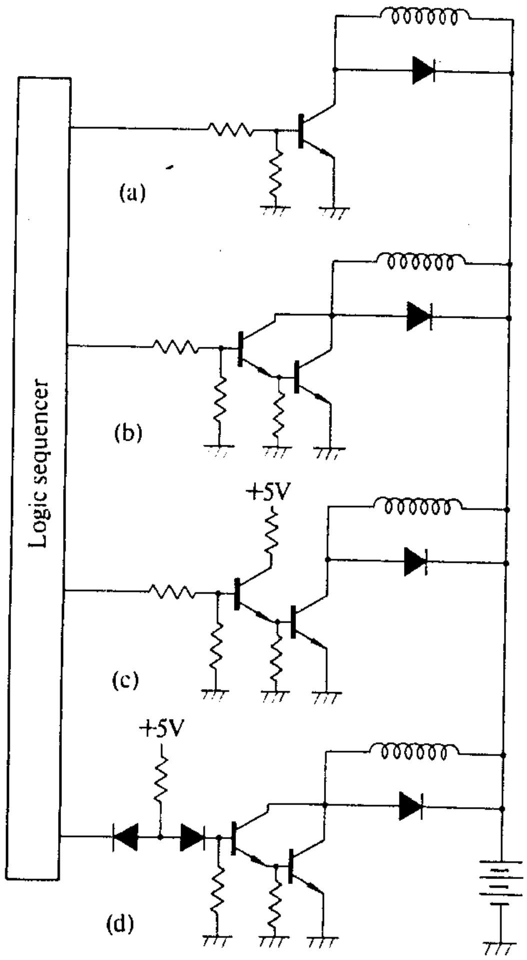
Figure 4-72. Three-level synchronous optimal PWM, steady-state waveforms: (a) voltage potential at the output of one inverter leg; (b) phase voltage; (c) phase current.

4. Stepper Motor Drives

Block diagram of the stepper drive system



The basic unipolar driver circuit



Improving the turn on/off time by an external resistor

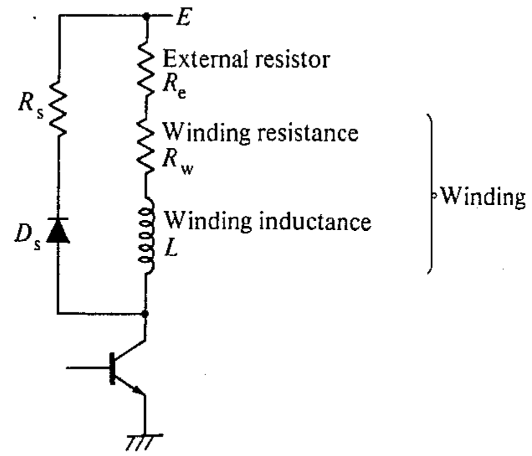


Fig. 5.24. Improving build-up by putting R_e in series with the winding and raising supply potential E.

Improving turn-off time by diode and zener diode

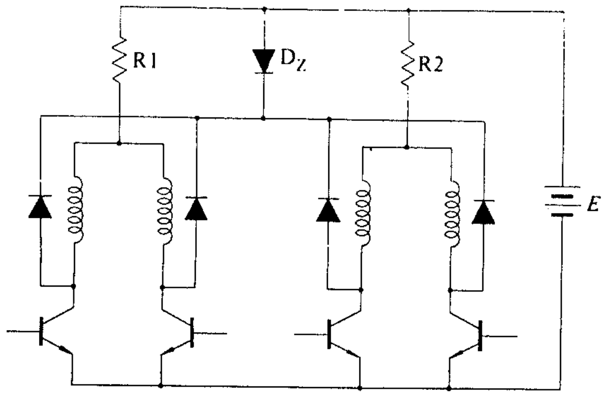


Fig. 5.20. Example of four-phase driver with zener diode suppressor.

Comparison of various schemes on the turn-off time improvement

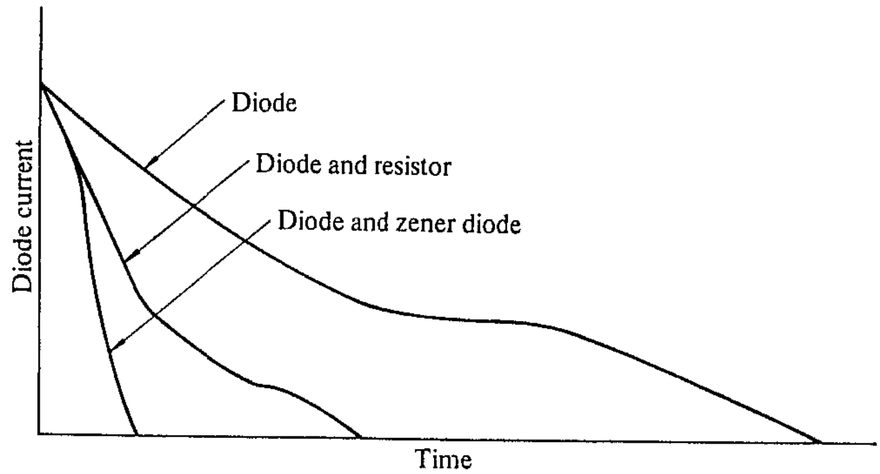


Fig. 5.19. Comparison of effects of various suppressor schemes.

Improving the turn-on time by dual voltage drive

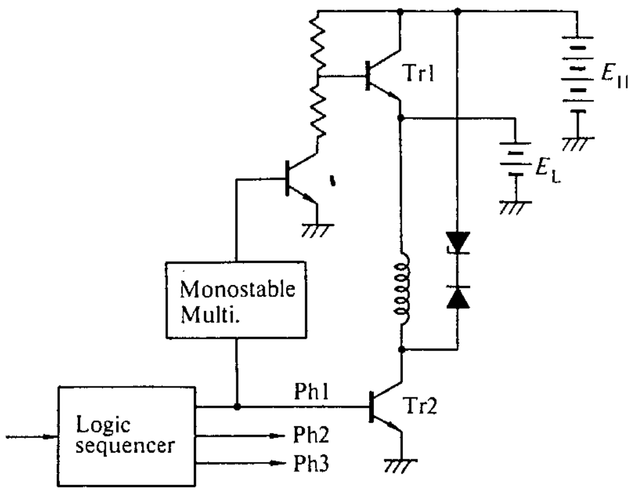


Fig. 5.25. Improvement of current build-up by means of dual voltage drive.

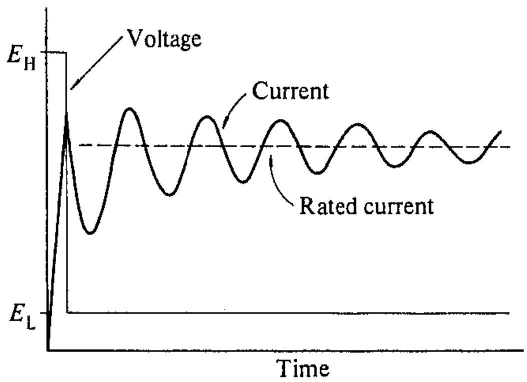


Fig. 5.26. Voltage and current waveforms in a dual voltage drive.

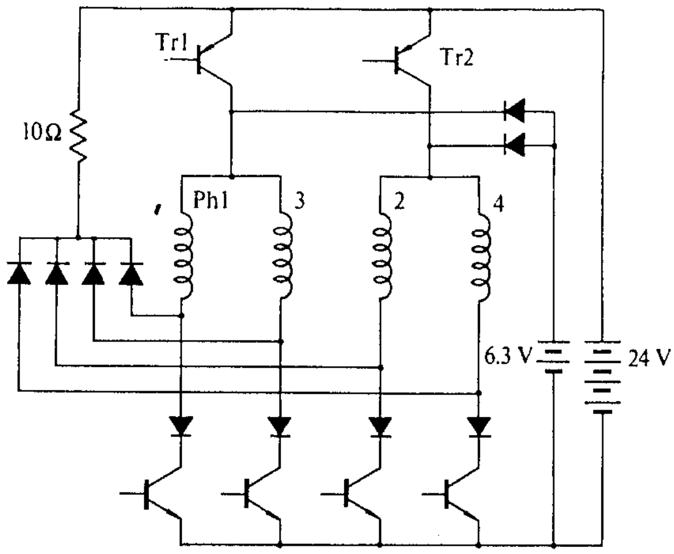


Fig. 5.27. A dual-voltage driver for the two-phase-on drive of a four-phase motor.

Improving the turn-on time by PWM

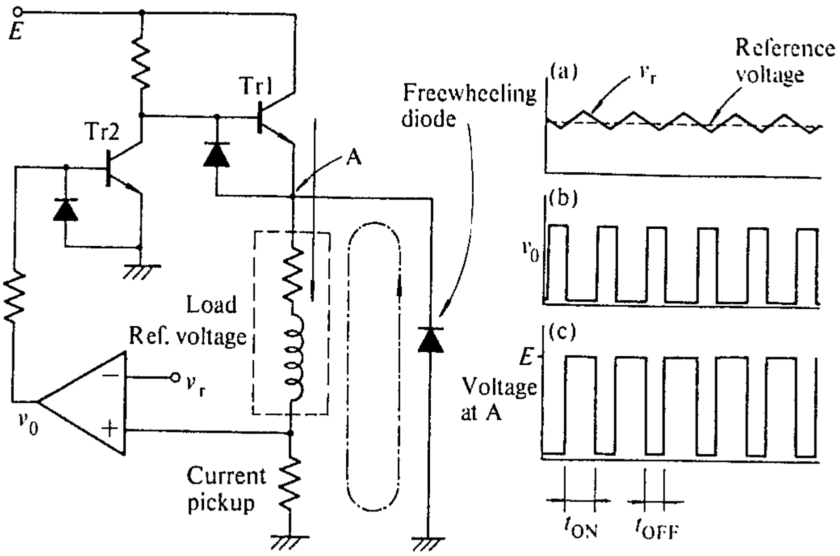
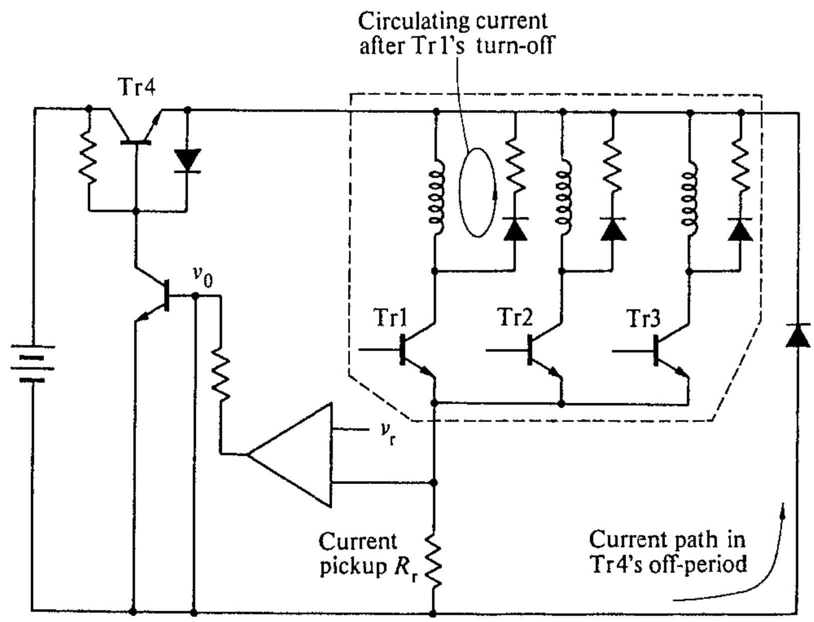
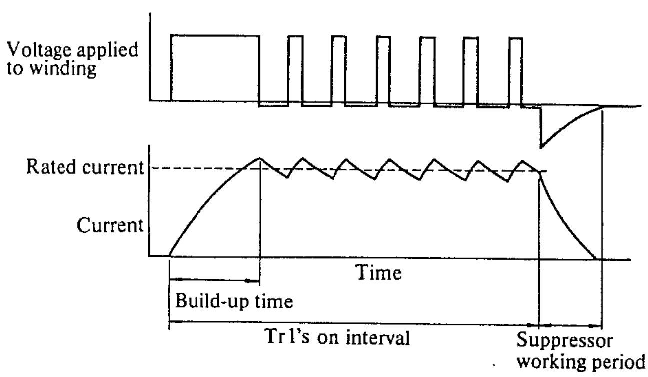


Fig. 5.32. PWM (= pulse width modulated) circuit and waveforms.



A driver scheme of the PWM type.



Chopper voltage and current waveform.

Using stepping profile for high speed motions

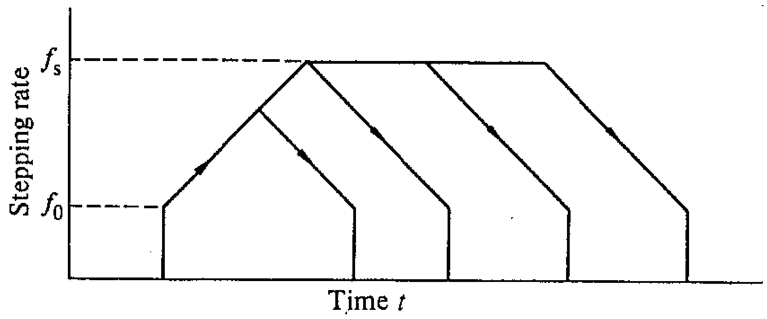


Fig. 5.48. Commanded speed vs. time profile relation.

Torque characteristics of stepping motor

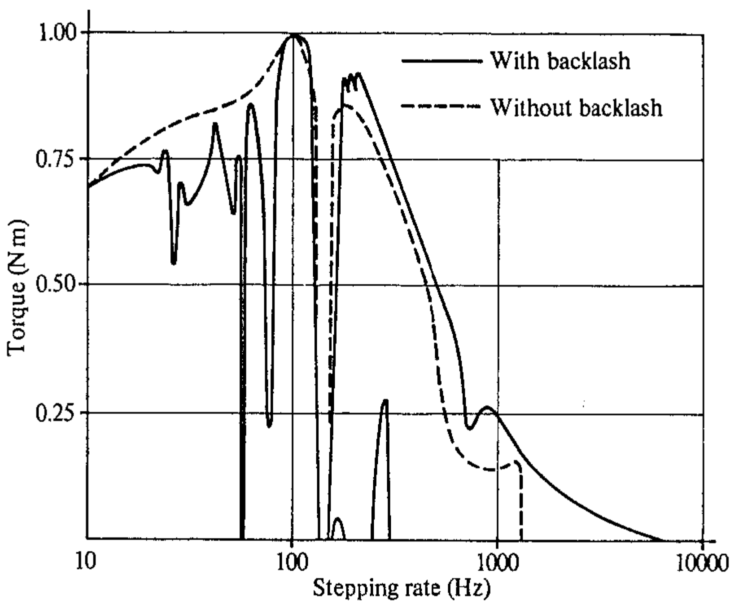


Fig. 6.7. Pull-out torque versus speed curves comparing the two cases: with backlash and without backlash.

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