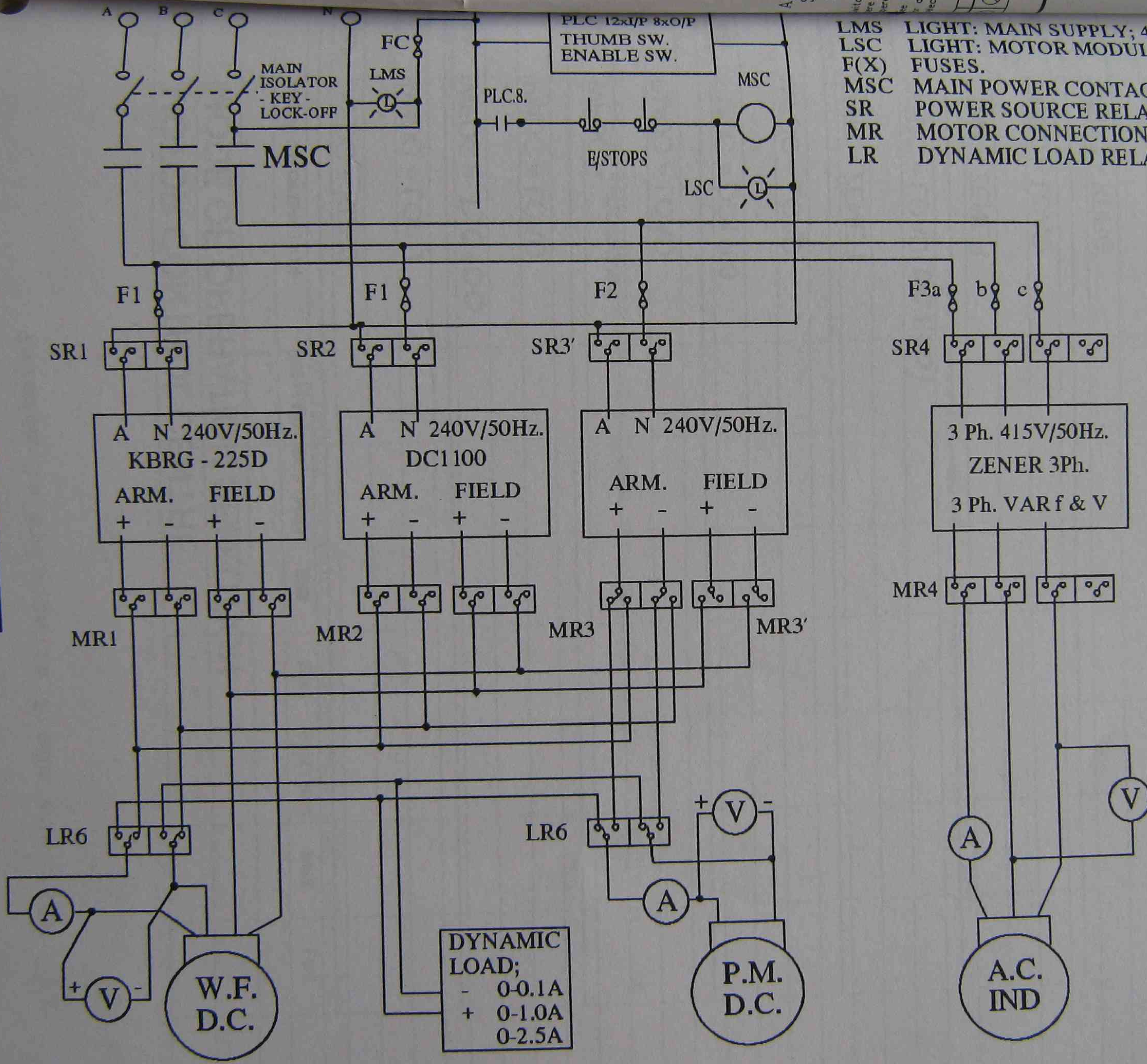
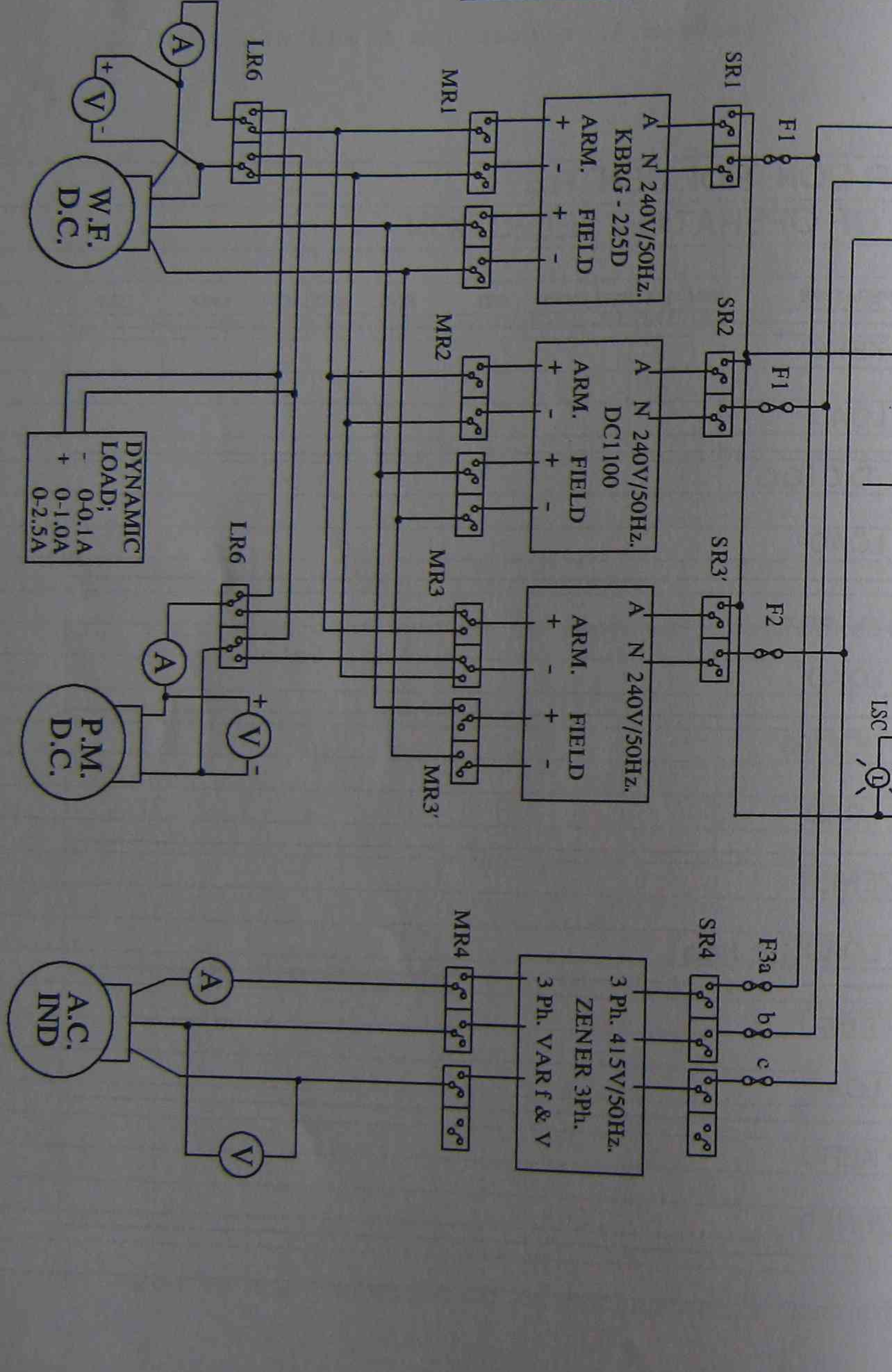
MOTOR CONTROL CENTRE.



LMS	LIGHT: MAIN SUPPLY; 415V/50Hz.
LSC	LIGHT: MOTOR MODULE ENERGISED.
F(X)	FUSES.
MSC	MAIN POWER CONTACTOR.
SR	POWER SOURCE RELAYS.
MR	MOTOR CONNECTION RELAYS.
LR	DYNAMIC LOAD RELAY.

MOTOR CONTROL CENTRE.



LMS LIGHT: MAIN SUPPLY; 415V/50Hz.
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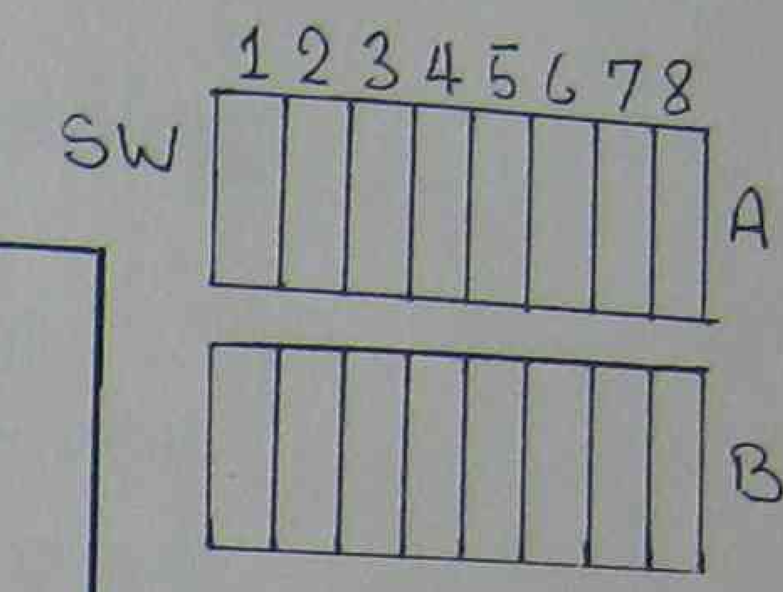
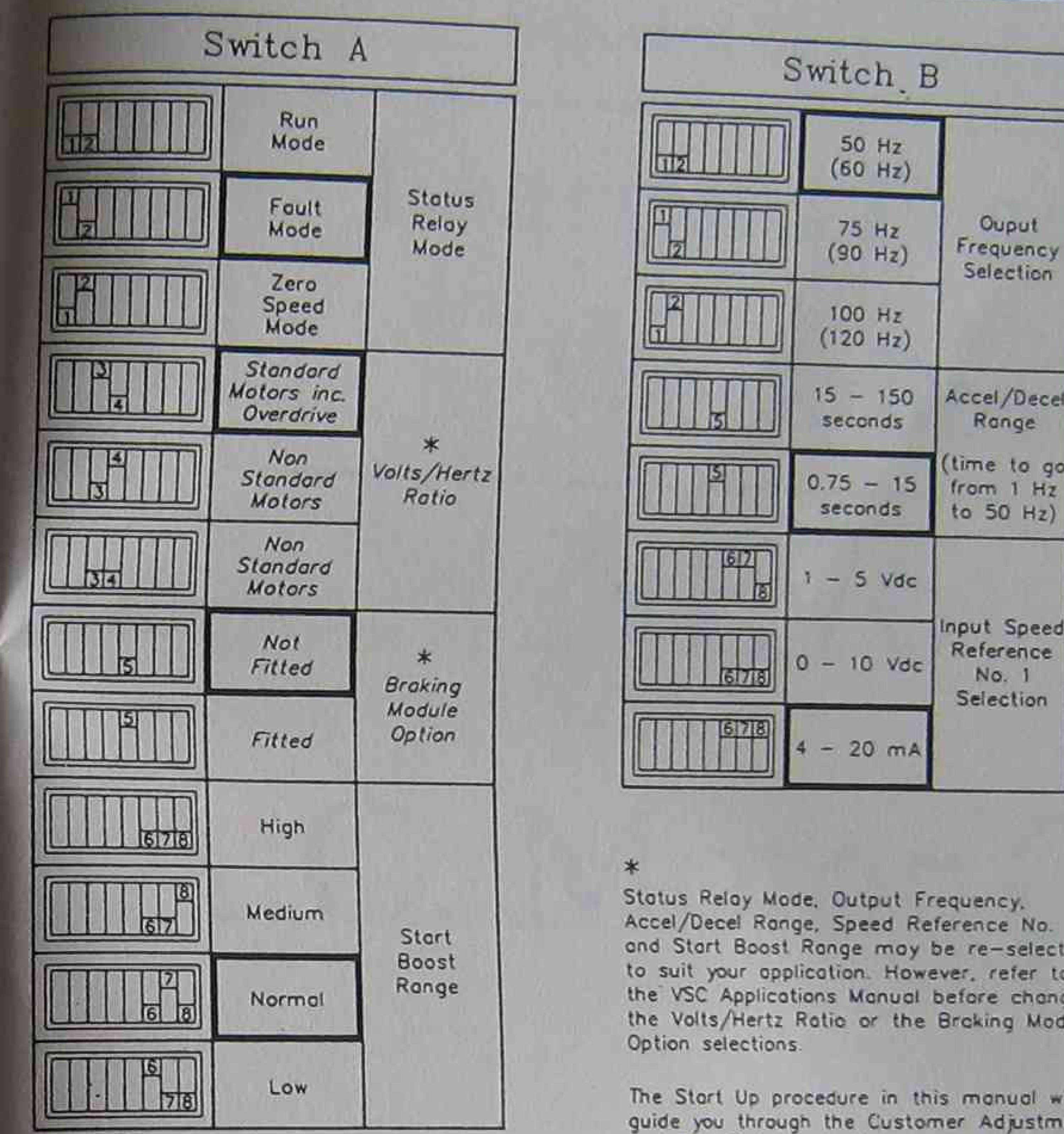
F(X) FUSES.
MSC MAIN POWER CONTACTOR.
SR POWER SOURCE RELAYS.
MR MOTOR CONNECTION RELAYS.
LR DYNAMIC LOAD RELAY.

ZENER 3 Ph. AC DRIVE - VSC

DIP SWITCH SETTINGS

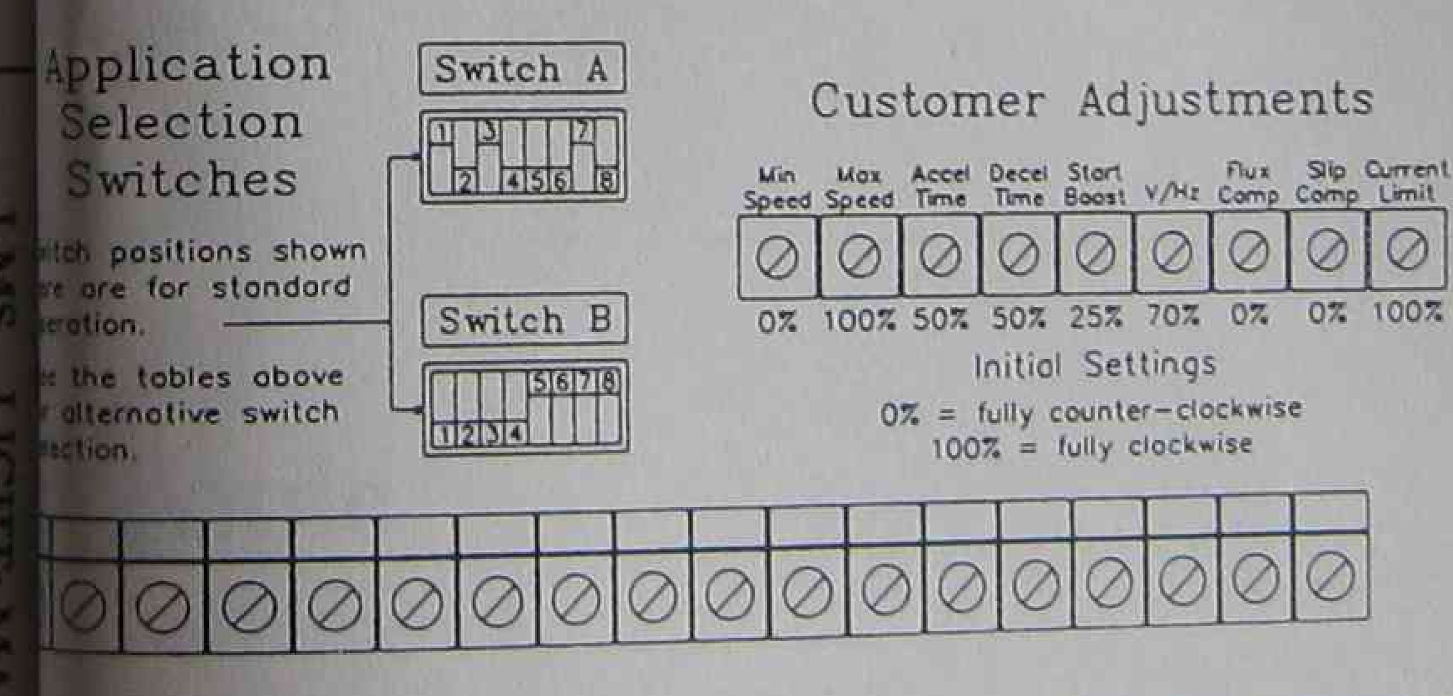


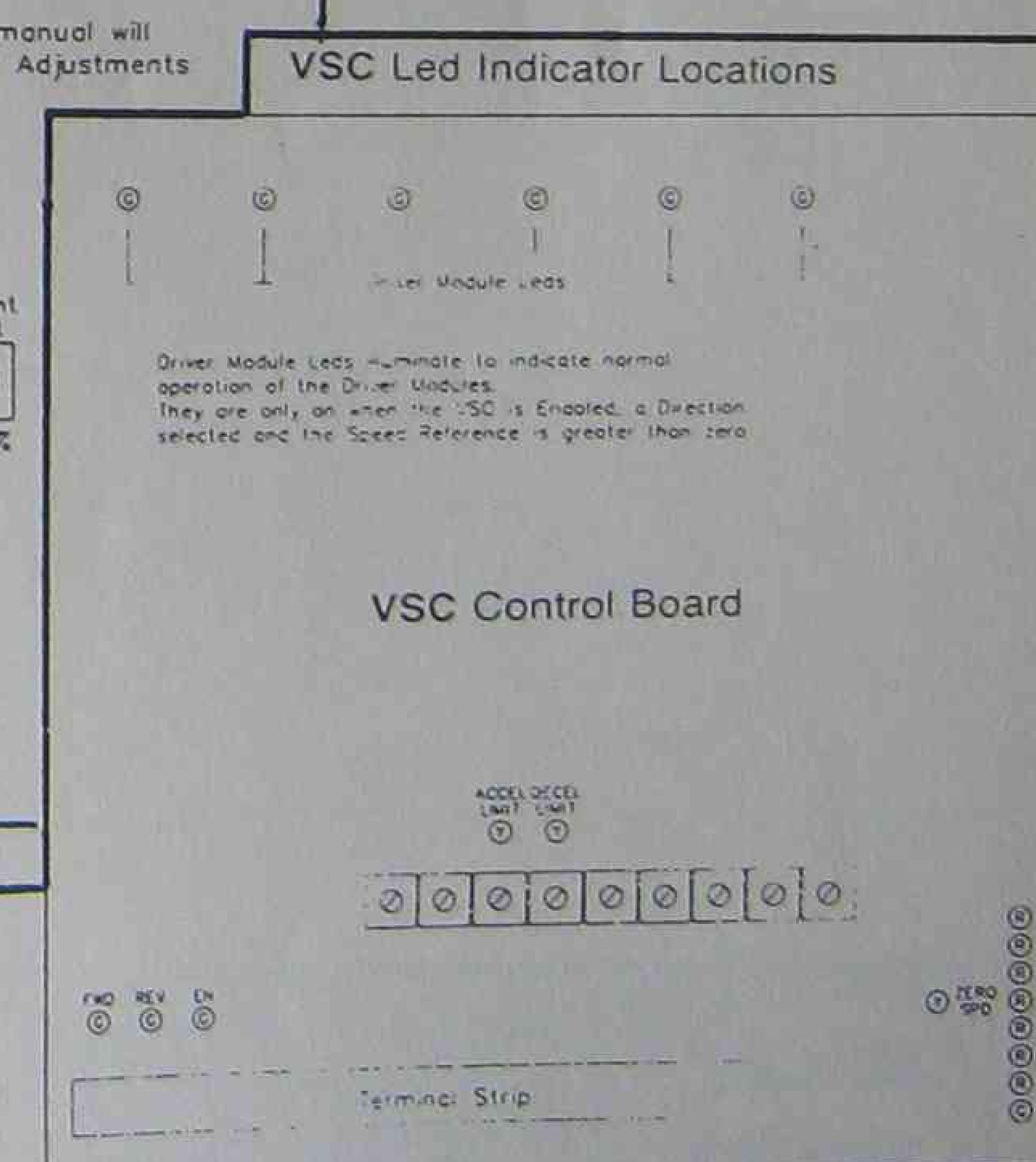


SPEED MIN ______
MAX ______
TIME ACCEL ______
DECEL ______
START BOOST ______
V/Hz ______
FLUX COMP ______
SLIP COMP ______
I LIMIT ______

* Status Relay Mode, Output Frequency, Accel/Decel Range, Speed Reference No. 1 and Start Boost Range may be re-selected to suit your application. However, refer to the VSC Applications Manual before changing the Volts/Hertz Ratio or the Braking Module Option selections.

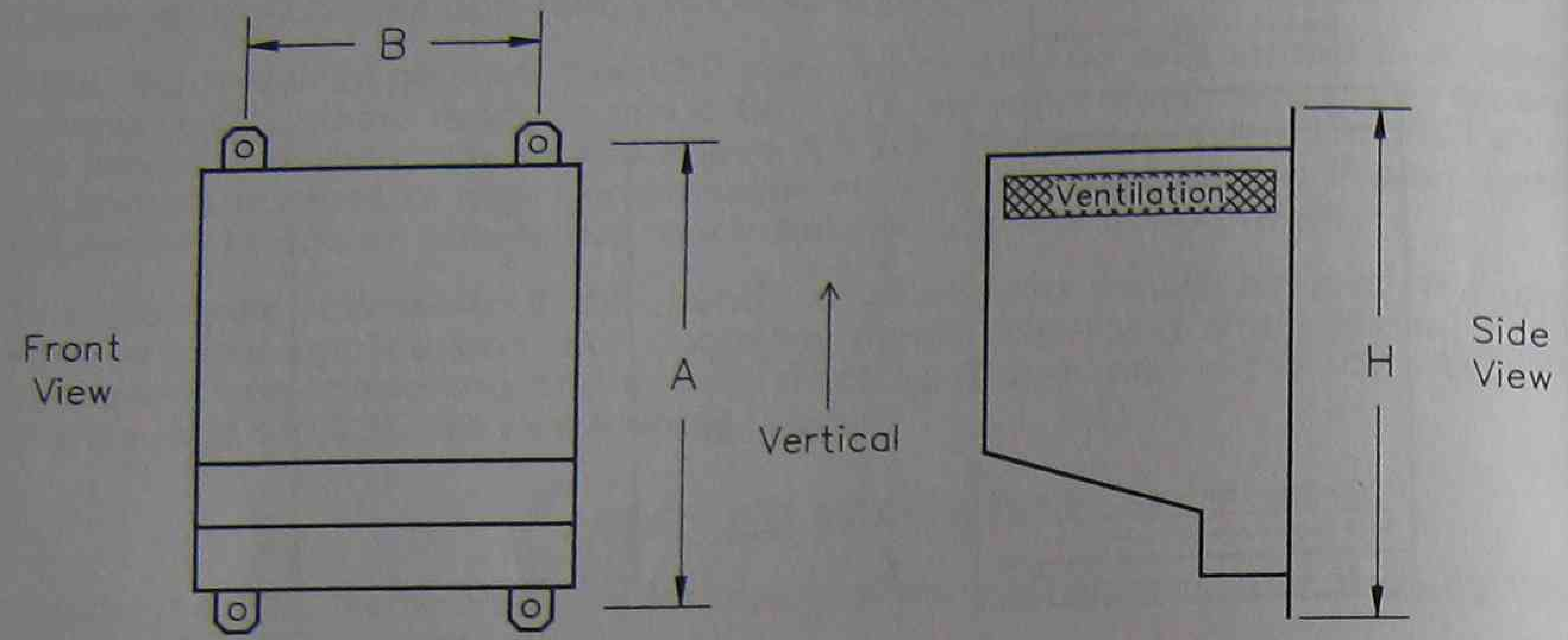
The Start Up procedure in this manual will guide you through the Customer Adjustments and final Switch selections.

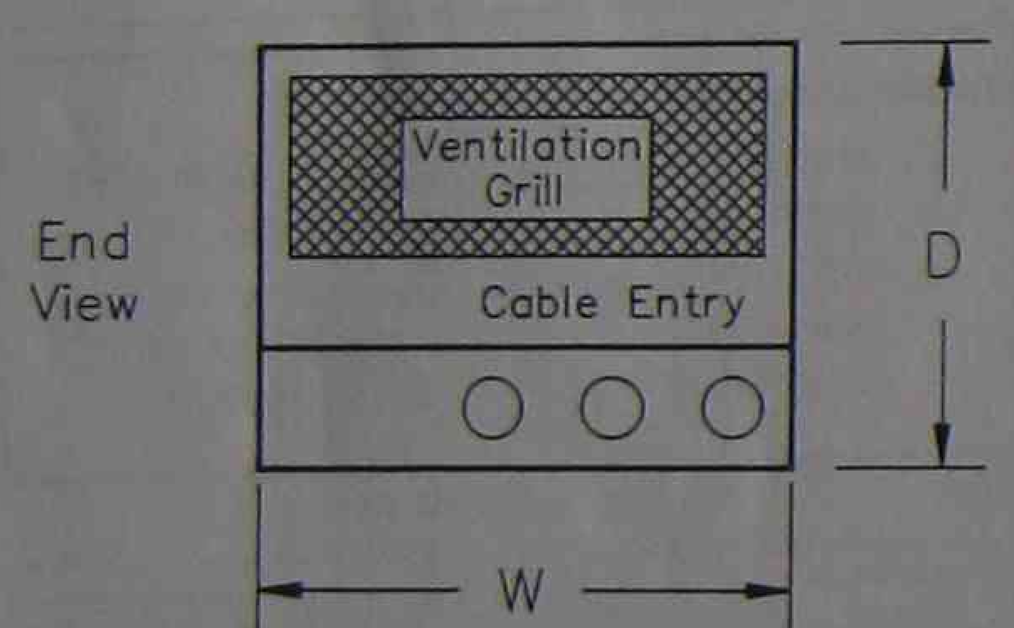




FWD	Forward Direction Selected	
REV	Reverse Direction Selected	
EN	VSC Enabled	
ACCEL LIMIT	Acceleration Limit Operating	
DECEL LIMIT	Deceleration Limit Operating	
ZERO SPD	VSC at Zero Speed	
EF	Earth Fault	Earth Fault in motor or motor wiring
UV	Under Voltage	Input Voltage less than 85% of Nameplate Voltage
OV	Over Voltage	Input Voltage or DC Buss Voltage excessive
OT	Over Temperature	Heatsink Temperature excessive
OC+	Over Current Plus	Output Current has exceeded maximum allowable
OC-	Over Current Minus	Regeneration Current has exceeded max. allowable
RT	Remote Trip	Remote Trip contact is open
	Power On	

VSC Enclosure Mechanical Installation and Physical Dimensions





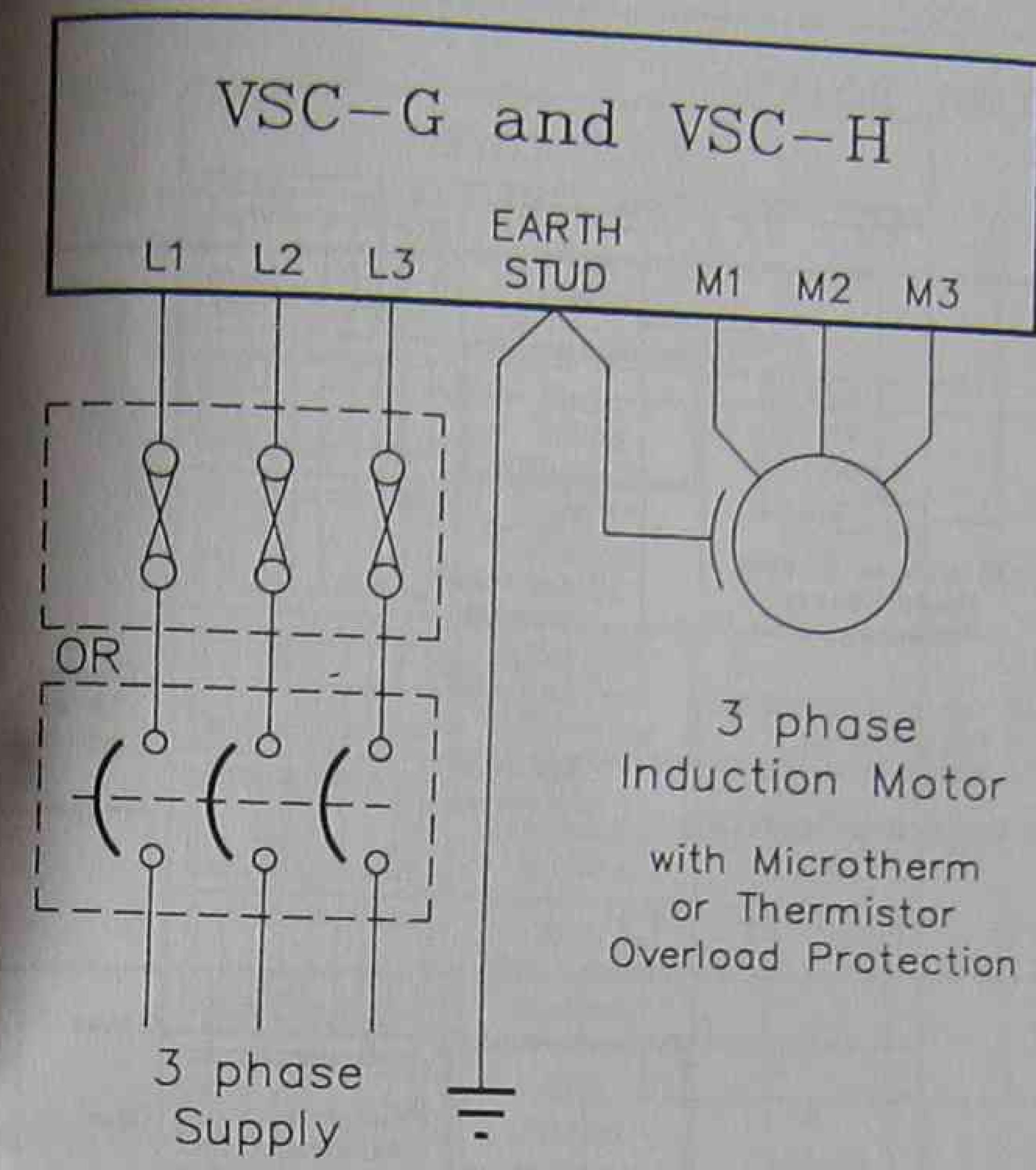
1. All dimensions are in mm.
2. Mounting holes are 8mm diameter.
3. Dimension tolerance: ±1mm.
4. Do not allow swarf or any other conductive material to enter the enclosure or damage may result.

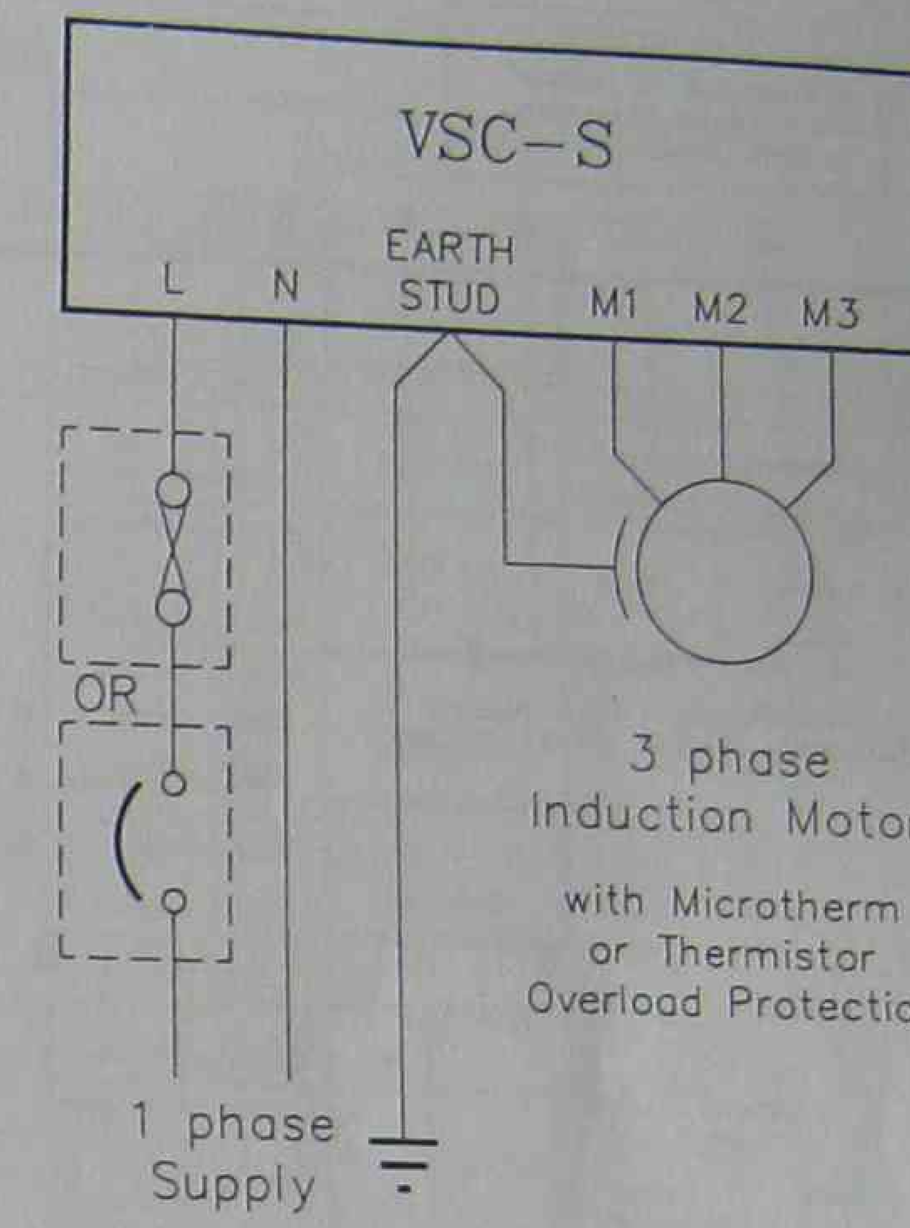
READ THIS FIRST

1. The VSC enclosure must be mounted in a Vibration Free location.
2. Protect the enclosure against dust build-up and dripping or sprayed liquids.
3. Operating Temperature: 0°C to 50°C.
4. Mount the enclosure vertically away from heat radiating sources.
5. Allow 100mm above, below and either side of the enclosure for ventilation.
6. Do not mount the enclosure in direct sunlight or on hot surfaces.
7. If the enclosure is mounted inside another enclosure, the total heat dissipation must be allowed for. Refer to the VSC Applications Manual.

Model Number	H mm	W mm	D mm	A mm	B mm	Weight kg
VSC-S3	445	280	200	420	185	8
VSC-S4	445	280	200	420	185	11
VSC-S5	445	280	200	420	185	12
VSC-G13	445	280	200	420	185	12
VSC-G17	520	400	200	495	230	19
VSC-G24	520	400	200	495	230	19
VSC-G32	520	400	200	495	230	19
VSC-G38	520	400	200	495	230	19
VSC-G44	920	400	265	890	230	35
VSC-G60	920	400	265	890	230	39
VSC-H3	445	280	200	420	185	8
VSC-H4	445	280	200	420	185	11
VSC-H5	445	280	200	420	185	12
VSC-H10	445	280	200	420	185	12
VSC-H13	445	280	200	420	185	12
VSC-H17	520	400	200	495	230	19
VSC-H24	520	400	200	495	230	19
VSC-H32	520	400	200	495	230	19
VSC-H38	920	400	265	890	230	35
VSC-H44	920	400	265	890	230	35

VSC Power Wiring Diagram





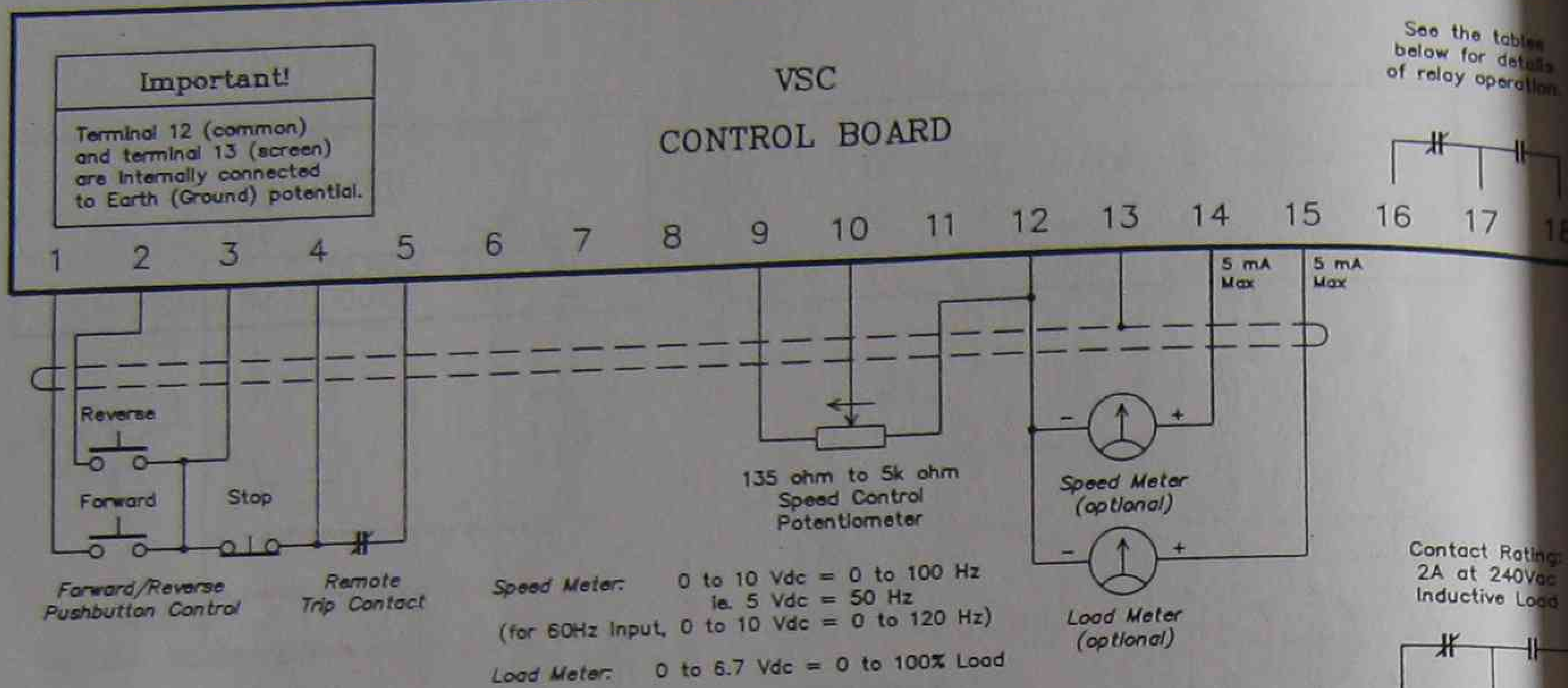
Recommended Fuse and Circuit breaker Ratings

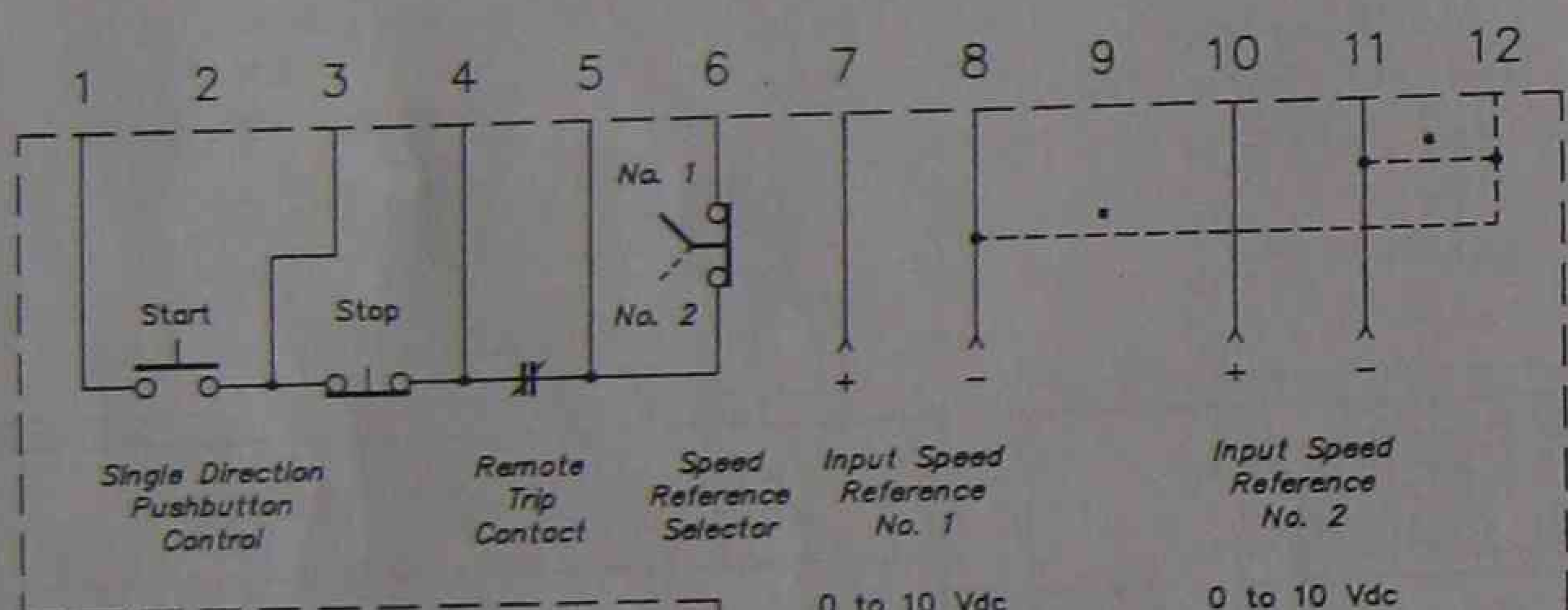
Model Number	Input Current		Fuse or C/B Rating
	Continuous	Intermittent	
VSC-S3	4.8 A	7.2 A	10 A
VSC-S4	6.6 A	9.9 A	10 A
VSC-S5	8.3 A	12.5 A	16 A
VSC-G13	14.3 A	15.7 A	16 A
VSC-G17	19.3 A	21.2 A	32 A
VSC-G24	26.4 A	29.1 A	32 A
VSC-G32	35.2 A	38.7 A	40 A
VSC-G38	41.8 A	46.0 A	63 A
VSC-G44	48.4 A	53.3 A	63 A
VSC-G60	66.0 A	72.6 A	80 A
VSC-H3	2.8 A	4.2 A	6 A
VSC-H4	4.4 A	6.6 A	10 A
VSC-H5	5.5 A	8.3 A	10 A
VSC-H10	11.0 A	16.5 A	20 A
VSC-H13	14.3 A	21.5 A	32 A
VSC-H17	19.3 A	28.9 A	32 A
VSC-H24	26.4 A	39.6 A	40 A
VSC-H32	35.2 A	52.8 A	63 A
VSC-H38	41.8 A	62.7 A	63 A
VSC-H44	48.4 A	72.6 A	80 A

READ THIS FIRST

1. Power Input and Output terminals are located in the bottom right hand corner of the controller.
2. EITHER Fuses OR a Circuit Breaker should be connected as shown above.
3. Locate the VSC Name Plate and check the Input Voltage BEFORE connecting mains power.
4. Microtherms or Thermistors should be installed in the motor for overload protection. Refer to the VSC control wiring diagram for trip contact connection details.
5. Input Voltage tolerance is −15% to +10% of nameplate value.
6. Do not connect contactor or relay coils to the VSC output terminals.
7. Cable sizes should be selected according to local codes or standards. The Input Current table may be used for cable selection.

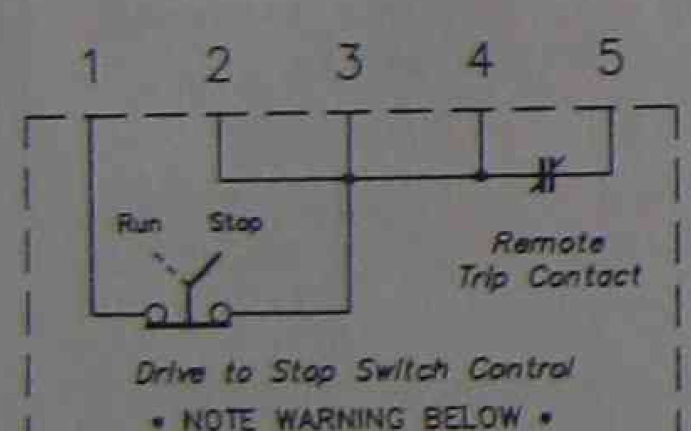
VSC Control Wiring Diagram

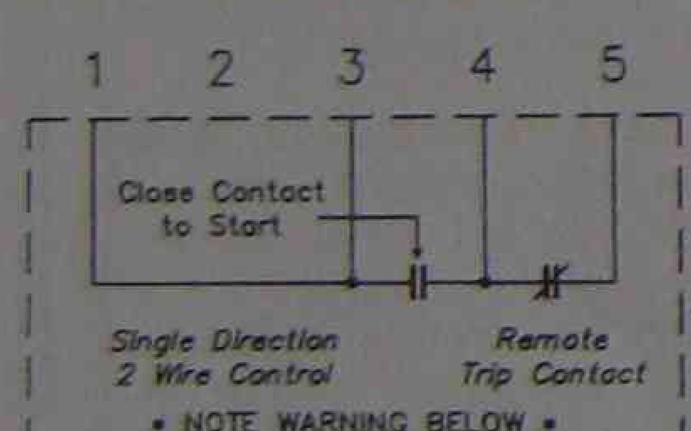


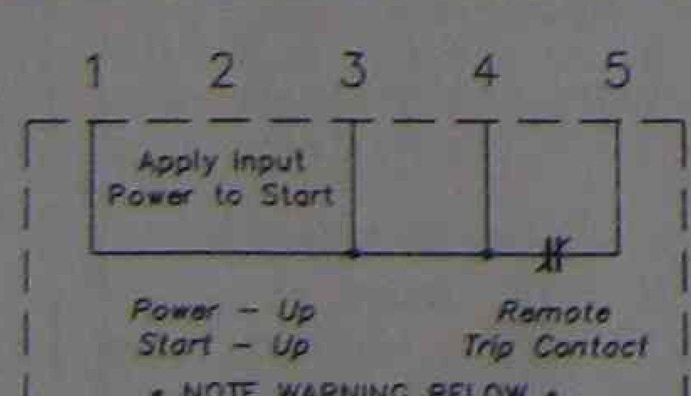


0 to 10 Vdc OR 4 to 20 mA OR 1 to 5 Vdc

0 to 10 Vdc OR a potentiometer may be connected as shown above.







* WARNING *

If the input power is interrupted, or the Remote Trip contact is reset, then an Undesired Start Up may occur.

If only Speed Reference No. 1 is required, terminals 5 and 6 should be bridged. If only Speed Reference No. 2 is to be used, terminals 5 and 6 should be left open.

The type of input signal for Speed Reference No. 1 may be selected by setting Switch B on the Control Board. Refer to page 8 for details on Speed Reference No. 1 input selection.

• These links should normally be installed. If you require differential inputs, remove the link between 8 and 12 (speed ref 1) and/or 11 and 12 (speed ref 2). Refer to the VSC Applications manual for more details.

Remote Trip Contact:
Normally a motor overload device such as a Thermistor Relay or a Microtherm would be connected to terminals 4 and 5 as shown. If this contact is opened, the VSC will be disabled and the Remote Trip Led will illuminate. If it is unused, terminals 4 and 5 should be linked.

Shielded Cable:
Shielded Cable must be used for all wiring to terminals 1 through 15.

Control Circuit Contact Rating:
24 Vdc at 0.1 A

	16–17	17–18
No Input Power	Closed	Open
Power On, No Fault	Open	Closed
Power On Fault Detected	Closed	Open

FAULT MODE

	16–17	17–18
No Input Power	Closed	Open
Power On, Zero Speed	Closed	Open
Power On, Speed > Zero	Open	Closed

ZERO SPEED MODE

	16–17	17–18
No Input Power	Closed	Open
Power On, Drive Stopped	Closed	Open
Power On, Drive Enabled and Direction Selected	Open	Closed

RUN MODE

VSC Adjustment Locations and Initial Settings

Switch A

Switch	Setting	Function
1 2	Run Mode	Status Relay Mode
1 / 2	**Fault Mode**	Status Relay Mode
2 / 1	Zero Speed Mode	Status Relay Mode
3 / 4	**Standard Motors inc. Overdrive**	* Volts/Hertz Ratio
4 / 3	Non Standard Motors	* Volts/Hertz Ratio
3 4	Non Standard Motors	* Volts/Hertz Ratio
5	**Not Fitted**	* Braking Module Option
5	Fitted	* Braking Module Option
6 7 8	High	Start Boost Range
8 / 6 7	Medium	Start Boost Range
7 / 6 8	**Normal**	Start Boost Range
6 / 7 8	Low	Start Boost Range

Switch B

Switch	Setting	Function
1 2	**50 Hz (60 Hz)**	Ouput Frequency Selection
1 / 2	75 Hz (90 Hz)	Ouput Frequency Selection
2 / 1	100 Hz (120 Hz)	Ouput Frequency Selection
5	15 – 150 seconds	Accel/Decel Range (time to go from 1 Hz to 50 Hz)
5	**0.75 – 15 seconds**	Accel/Decel Range (time to go from 1 Hz to 50 Hz)
6 7 / 8	1 – 5 Vdc	Input Speed Reference No. 1 Selection
6 7 8	0 – 10 Vdc	Input Speed Reference No. 1 Selection
6 7 8	**4 – 20 mA**	Input Speed Reference No. 1 Selection

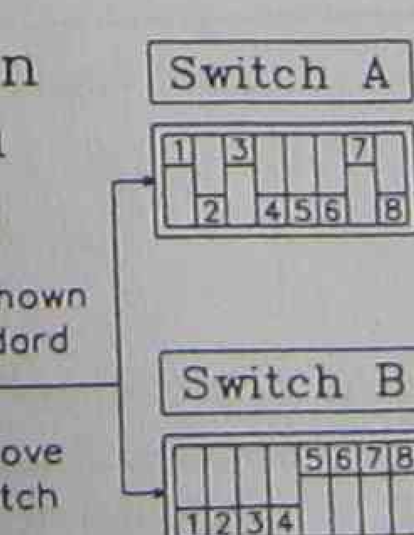
*
Status Relay Mode, Output Frequency, Accel/Decel Range, Speed Reference No. 1 and Start Boost Range may be re-selected to suit your application. However, refer to the VSC Applications Manual before changing the Volts/Hertz Ratio or the Braking Module Option selections.

The Start Up procedure in this manual will guide you through the Customer Adjustments and final Switch selections.

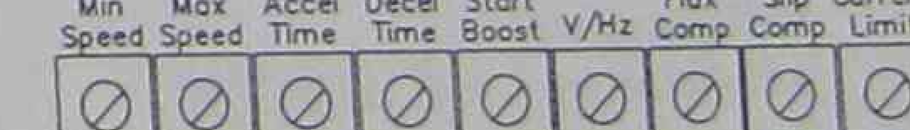
Application Selection Switches

Switch positions shown here are for standard operation.

See the tables above for alternative switch selection.



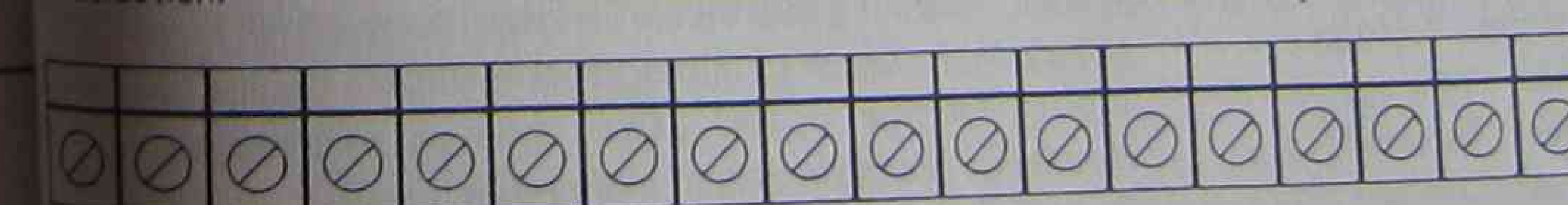
Customer Adjustments



Min Speed	Max Speed	Accel Time	Decel Time	Start Boost	V/Hz	Flux Comp	Slip Comp	Current Limit
0%	100%	50%	50%	25%	70%	0%	0%	100%

Initial Settings

0% = fully counter-clockwise
100% = fully clockwise



SLIP COMPENSATION ADJUSTMENT

The Slip Compensation feature provides more accurate speed holding for the induction motor by sensing motor load and automatically varying the output frequency and voltage to compensate for the resulting change in motor slip.

If accurate speed holding is of little importance in your application, there is no need to adjust Slip Compensation. Leave it set fully counter-clockwise.

The following procedure describes how to adjust Slip Compensation for optimum speed regulation. In order to complete the procedure, you will need to measure the motor shaft speed, or the speed of a relevant part of the machine it is driving. This is usually done with a Hand Tachometer.

Run the motor at the normal operating speed for your application. If you are unsure run the motor at about 40 Hz (about 4 Vdc between terminals 14 and 12).

Start with the motor unloaded (or the lowest likely load). Measure the motor speed (or machine speed) and record the result. Then run the motor fully loaded (or the highest likely load). Measure the motor or machine speed, it should be lower than the unloaded speed. Increase the Slip Compensation adjustment until the loaded and unloaded speeds are the same.

Repeat this process until the lightly loaded speed is the same as the heavily loaded speed.

FLUX COMPENSATION ADJUSTMENT

Flux Compensation provides energy savings by automatically reducing the motor "magnetization" or flux whenever the motor is not fully loaded. It is most effective when the motor has been "Over Sized" for the load it is required to drive. Motor heating is also reduced.

Maximum benefit can be obtained when the Low or Normal Start Boost ranges are selected. Flux Compensation has little or no effect when the High Start Boost range is selected or if the motor is always required to deliver full load.

Run the motor at the normal operating speed for your application. If you are unsure run the motor at about 40 Hz (about 4 Vdc between terminals 14 and 12).

Use a clamp-on ammeter (tong tester) to measure the motor phase current.

Increase the Flux Compensation adjustment. This should reduce the motor current. If not, your motor is fully loaded and no benefit can be obtained. If the current does decrease, advance the Flux Compensation adjustment until the current is at a minimum.

If the motor becomes unstable or the current begins to fluctuate, reduce the Flux Compensation adjustment until the motor operates normally.

This completes the start up and adjustment of your VSC.

VSC Start-up Trouble Shooting Guide

Symptom	Cause	Remedy
PWR Led does not illuminate.	Input Power Wiring not connected properly. Input Voltage not within specification.	Check Input Power Wiring Refer to the VSC Power Wiring diagram. Measure Input Voltage at Input Terminals Check against Specification Label.
EN and FWD or REV Leds do not illuminate when the start Circuit is activated. No other Fault Leds illuminate.	Control Wiring not connected properly. External fault in control wiring.	Check all wiring to terminals 1,2,3 and 4. Refer to the VSC Control Wiring Diagram. Check operator control devices.
Controller will not start and the RT Led illuminates.	Remote Trip contact is not closed.	Check the wiring to the Remote Trip contact, it should be closed. If no RT contact is used, bridge terminals 4 and 5.
ZSP Led remains on when the speed reference is increased.	Speed Control signal not properly connected. Incorrect Speed Input selected.	Check wiring on terminals 7,8,9,10,11 & 12. Refer to the VSC Control Wiring Diagram. If only Speed Reference No 1 is required, terminals 5 and 6 should be bridged. If only Speed Reference No 2 is to be used terminals 5 and 6 should be open. If a Speed Reference Selector Switch is installed, be sure it is properly selected.
Motor does not rotate when the VSC is started and the speed signal is increased.	Insufficient Start Boost. Incorrect V/Hz Range selection. Incorrect output frequency selection. Incorrect Start Boost Range selection. Motor incorrectly wired. Incorrect motor voltage.	Increase Start Boost Adjustment. Check V/Hz Range against VSC Adjustment diagram. Check Output Frequency Range against VSC Adjustment Diagram. Check Start Boost Range against VSC Adjustment Diagram. Check motor wiring. Check motor voltage.
The Accel Limit Led illuminates continuously when the speed signal is advanced. The motor will not accelerate.	Start Boost too high. Current Limit set too low. Accel Time set too short. Incorrect V/Hz range. Incorrect Start Boost range. Motor Rating is much higher than VSC rating. Motor shaft jammed. Motor mechanically overloaded. Motor incorrectly wired. Incorrect motor voltage.	Reduce Start Boost Adjustment. Increase Current Limit adjustment. Increase Accel Time adjustment. Check V/Hz Range selection. Check Start Boost Range selection. Use a VSC with a rating within 75% of the motor rating. Check mechanical drive system. Check actual mechanical load is within the motor's capacity at the required speed. Check motor wiring. Check motor voltage.
Decel Limit Led remains on during deceleration. The motor will not decelerate.	Motor is continuously over-hauling. Motor rating is much higher than VSC rating.	Fit a Braking Module. Use a VSC with a rating within 75% of the motor rating.
Motor does not run at the desired speed.	Incorrect Frequency Range selection. Min Speed adjustment. Max Speed adjustment. Speed Reference.	Check selection of Frequency Range. Check Min Speed adjustment. Check Max Speed adjustment. Check Speed Reference is correct.

VSC Start-up Trouble Shooting Guide

Symptom	Cause	Remedy
OV Led illuminates.	Input Voltage is not within specification. Decel Time too short.	Check Input Voltage at input terminals, measure all phases. Increase the Decel time.
UV Led illuminates.	Input Voltage is not within specification.	Check Input Voltage at input terminals. Make sure all phases are present.
OC+ Led illuminates.	Start Boost too high. Incorrect Start Boost Range selected. Incorrect V/Hz Range selected. Accel Time too short. Short circuit in motor or motor wiring. Open Circuit in motor wiring.	Reduce Start Boost Adjustment. Check Start Boost Range selection. Check V/Hz range selection. Increase Accel time. Check motor and motor wiring for faults. Check motor wiring for faults.
OC– Led illuminates.	Braking Module incorrectly fitted. Short circuit in motor or motor wiring. Open circuit in motor wiring.	Check installation of Braking Module. Check motor and motor wiring for faults. Check motor wiring for faults.
OT Led illuminates.	Ventilation problem. Start Boost is high and motor is running at low speed for long periods. Incorrect V/Hz Range selection. High Ambient Temperature.	Check ventilation. Consult the VSC Applications Manual for details relating to high Start Boost settings. Incorrect use of Start Boost may result in motor overheating. Check V/Hz Range selection. Ambient temperature must be below 50°C for the VSC to operate.
EF Led illuminates.	Earth Fault in motor or motor wiring.	Check motor and motor wiring for faults.
Motor is unstable.	Incorrect V/Hz range selection. Flux Comp too high. Slip Comp too high. Accel time too short. Decel time too short.	Check V/Hz range selection. Reduce Flux Comp adjustment. Reduce Slip Comp adjustment. Increase Accel time adjustment. Increase Decel time adjustment.
Excessive motor heating.	Start Boost is high and motor is running at low speed for long periods. Incorrect V/Hz Range selection. Motor speed is too high. Motor is overloaded. Motor incorrectly wired. Incorrect motor voltage.	Do Not run the motor at low speeds for long periods with high Start Boosts unless the motor has been suitably derated. Refer to the Applications Manual for details. Check the V/Hz Range selection. Check the frequency range selection. Check that the motor is not overloaded. Check motor wiring. Check motor voltage.

Sydney Institute of Technology

School of Electrotechnology

Learners Practical Work Book

Module NE76

A.C. Motor Control

Area ....

Topic ....

Session No. Mo H

For further information on this module, or this subject contact Jim Hafford, (02) 217 3620, Bld. K. Ultimo, S.I.T.

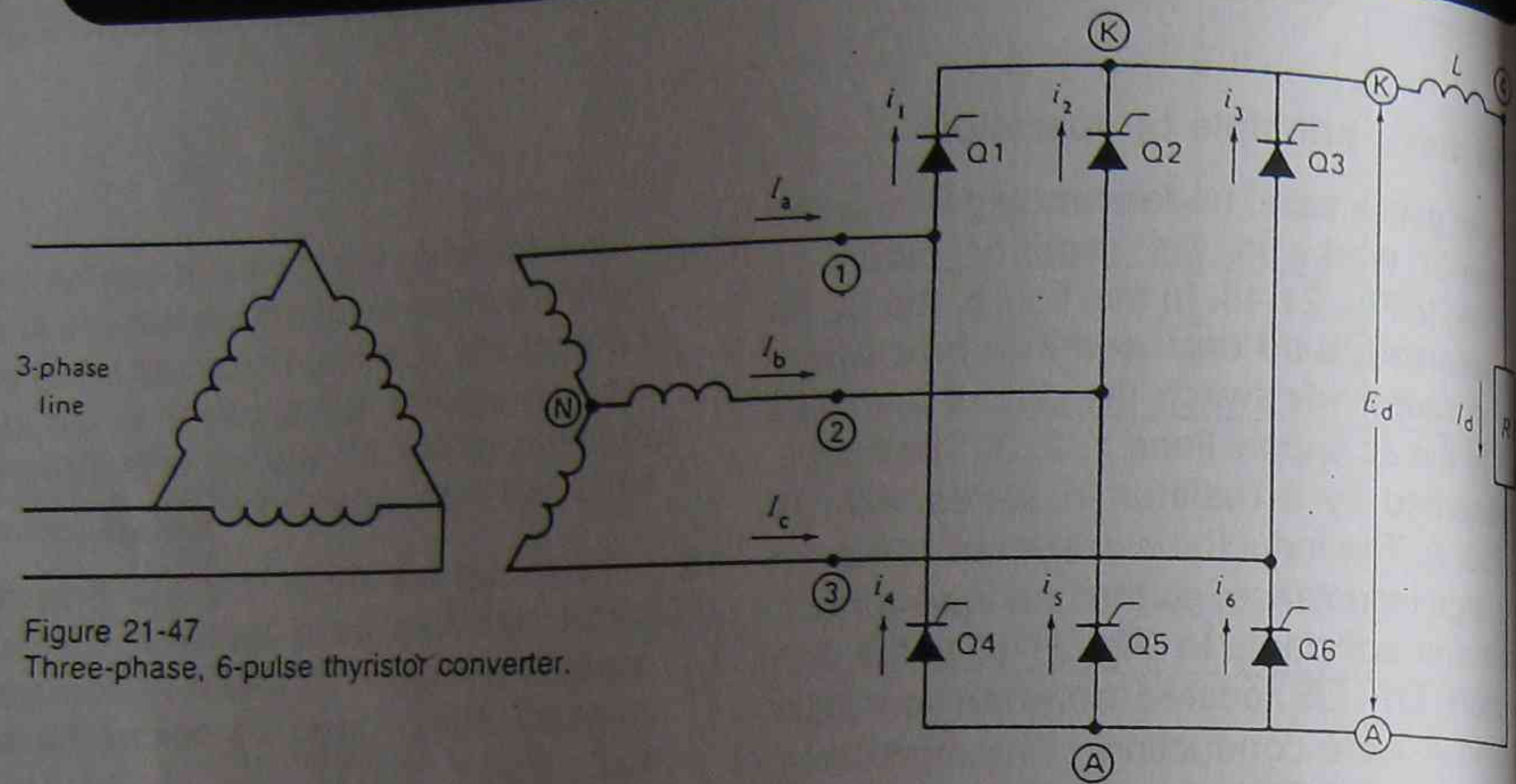


Figure 21-47
Three-phase, 6-pulse thyristor converter.

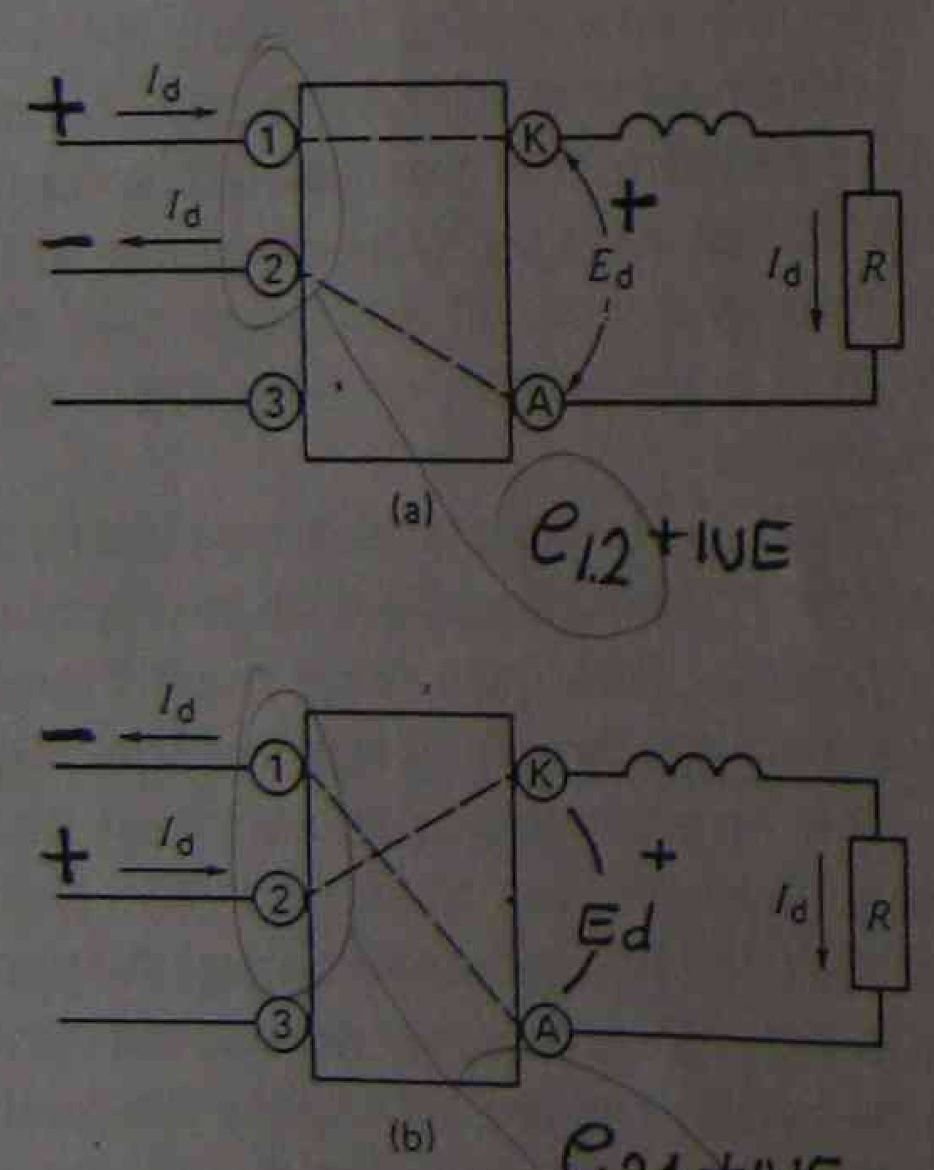


Figure 21-48
Rectifier mode (see Fig. 21-47)
a. Q1 and Q5 conducting.
b. Q2 and Q4 conducting.

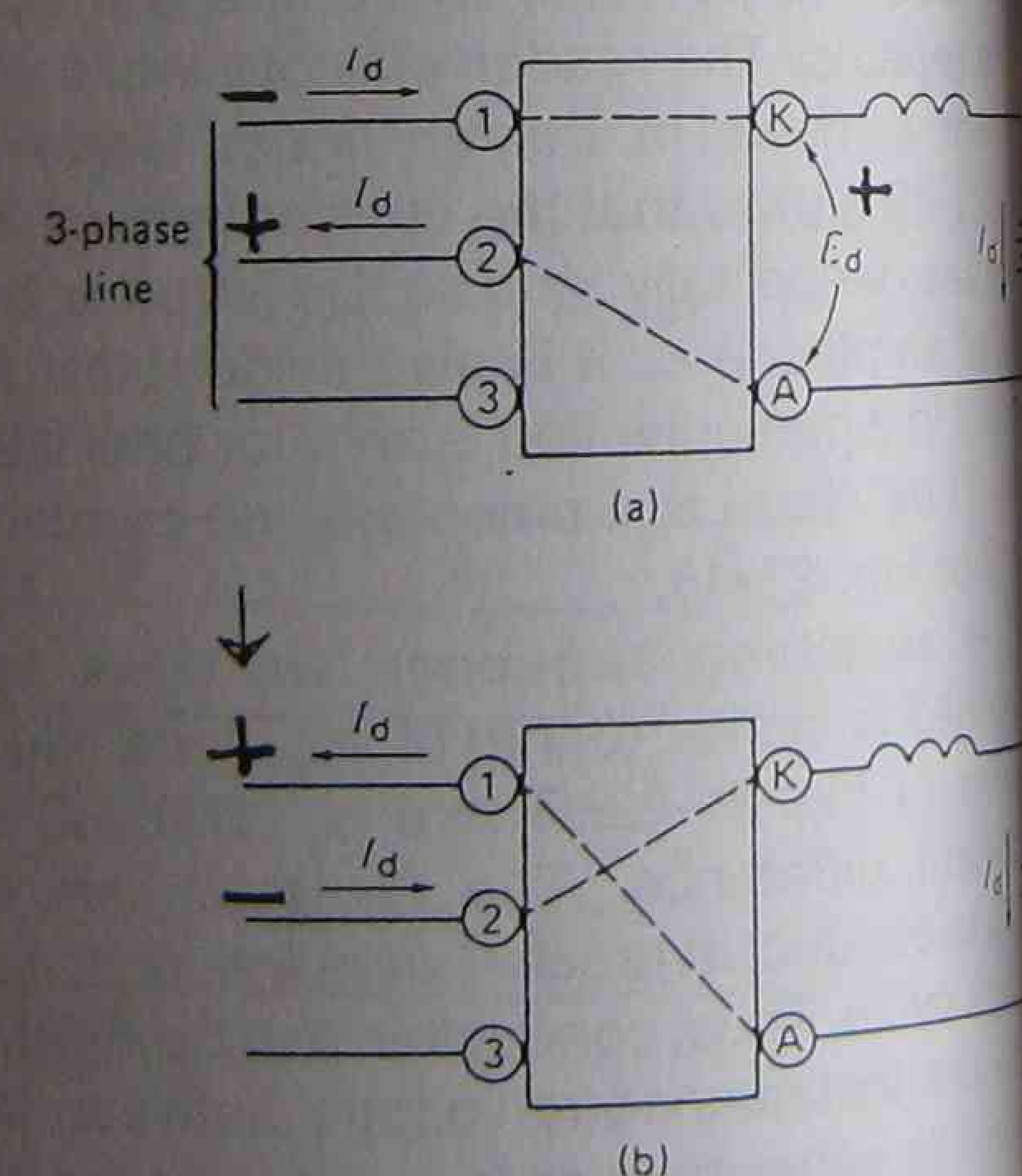
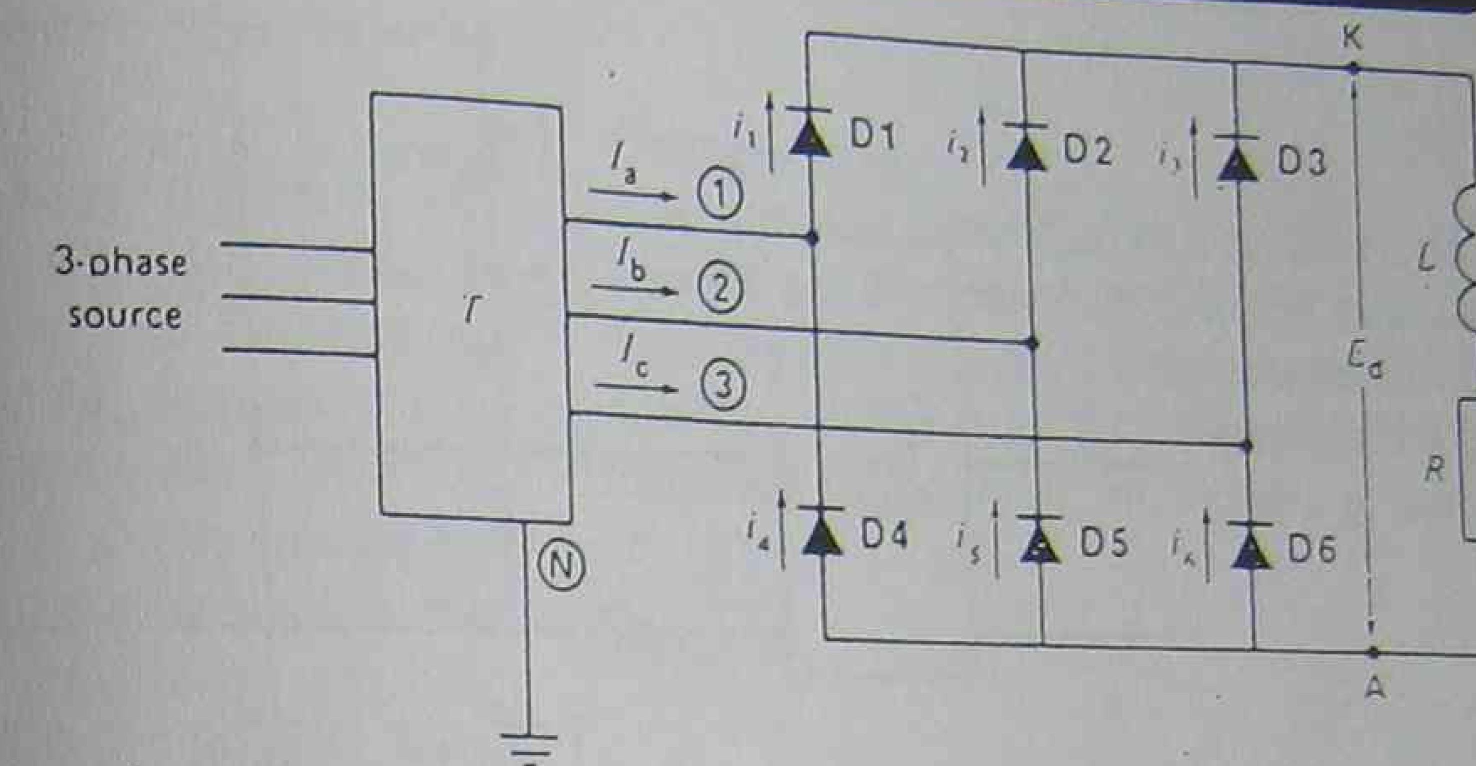
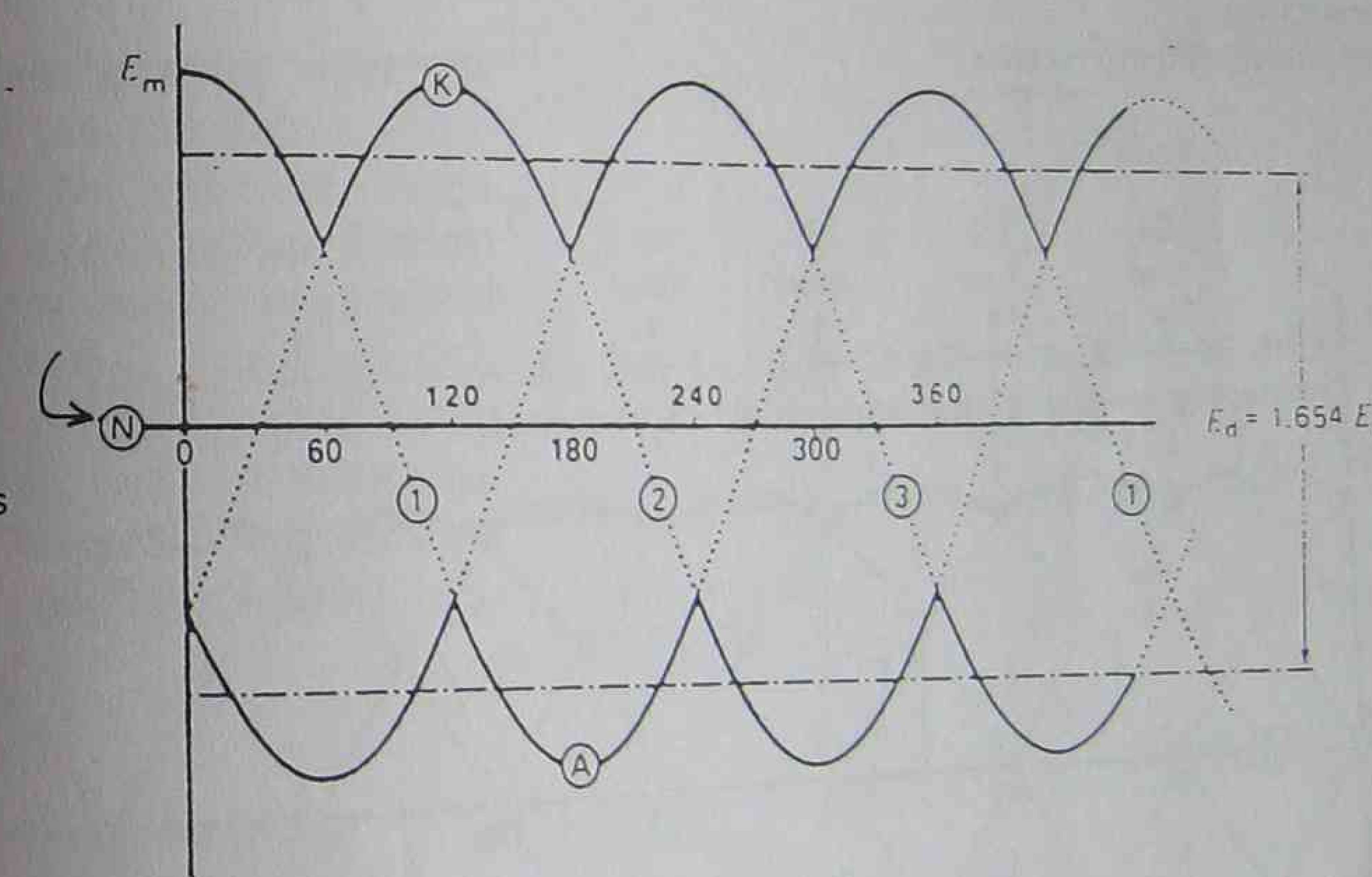


Figure 21-49
Inverter mode (see Fig. 21-47)
a. Q1 and Q5 conducting.
b. Q2 and Q4 conducting.

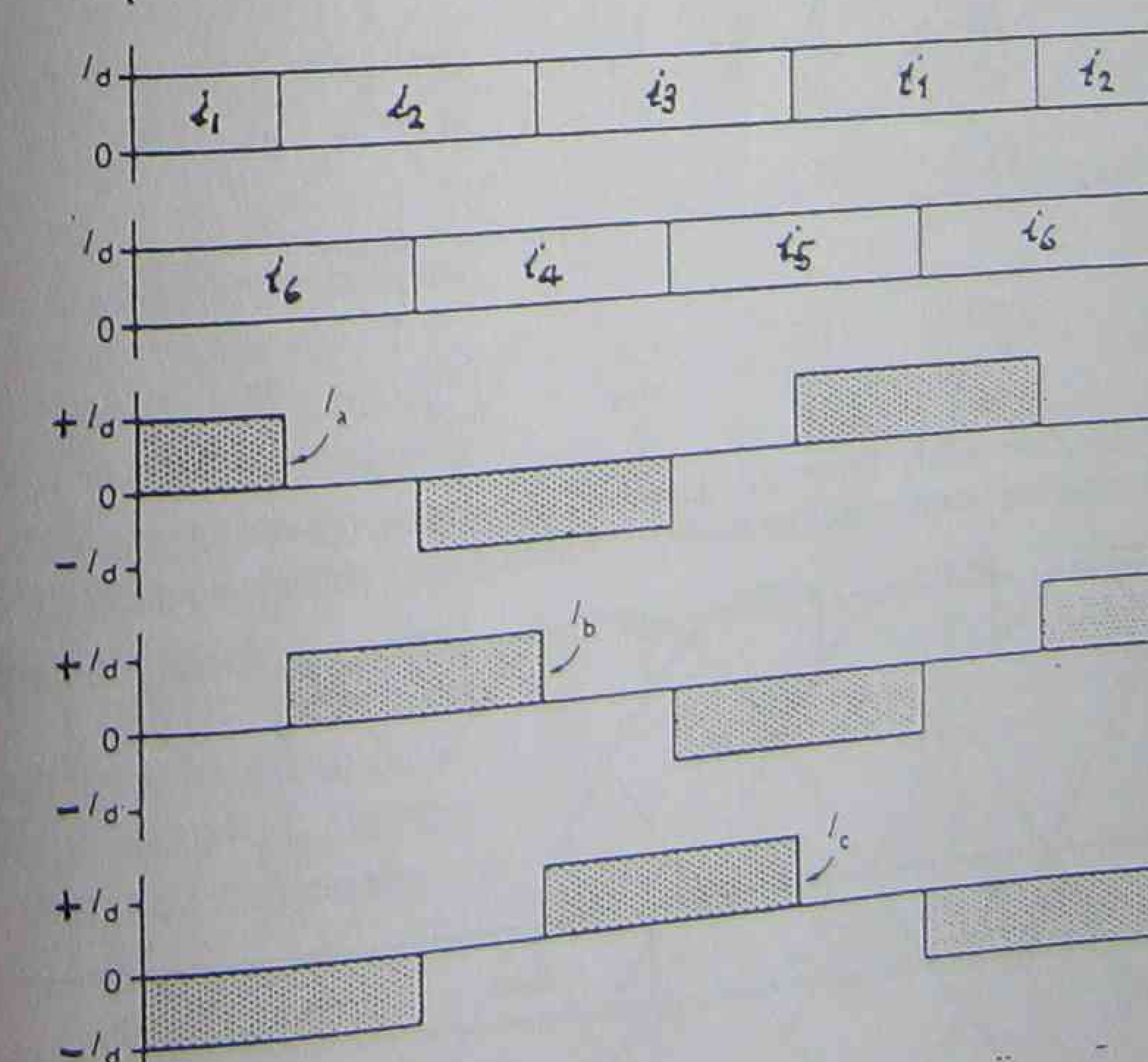
Because we can initiate conduction whenever we please, the thyristors enable us to vary the dc output voltage when the converter operates in the rectifier mode. The ...



...ure 21-19
...ree-phase, 6-pulse rectifier
...th inductive filter.



...ure 21-20
...ltage and current waveforms
... Fig. 21-19.



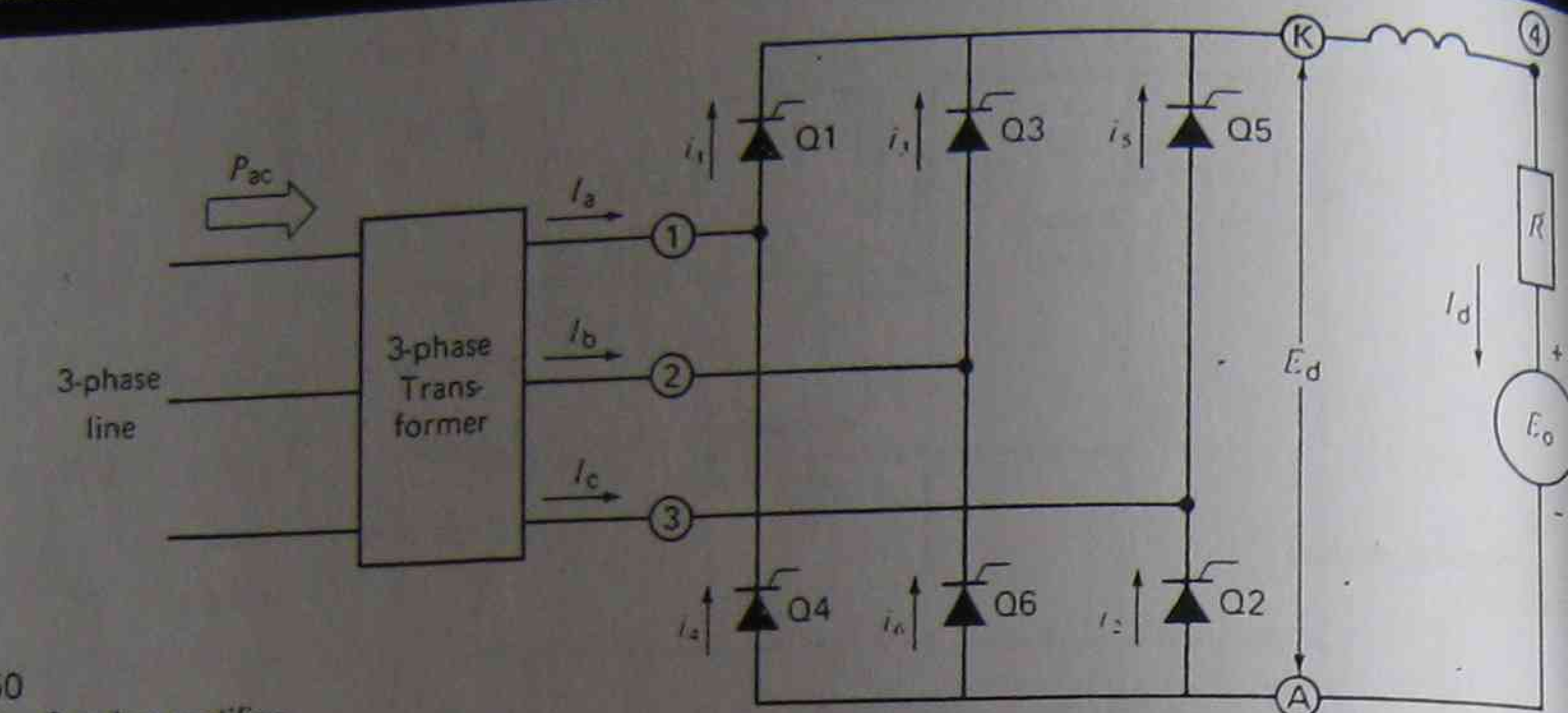


Figure 21-50
Three-phase, 6-pulse rectifier.

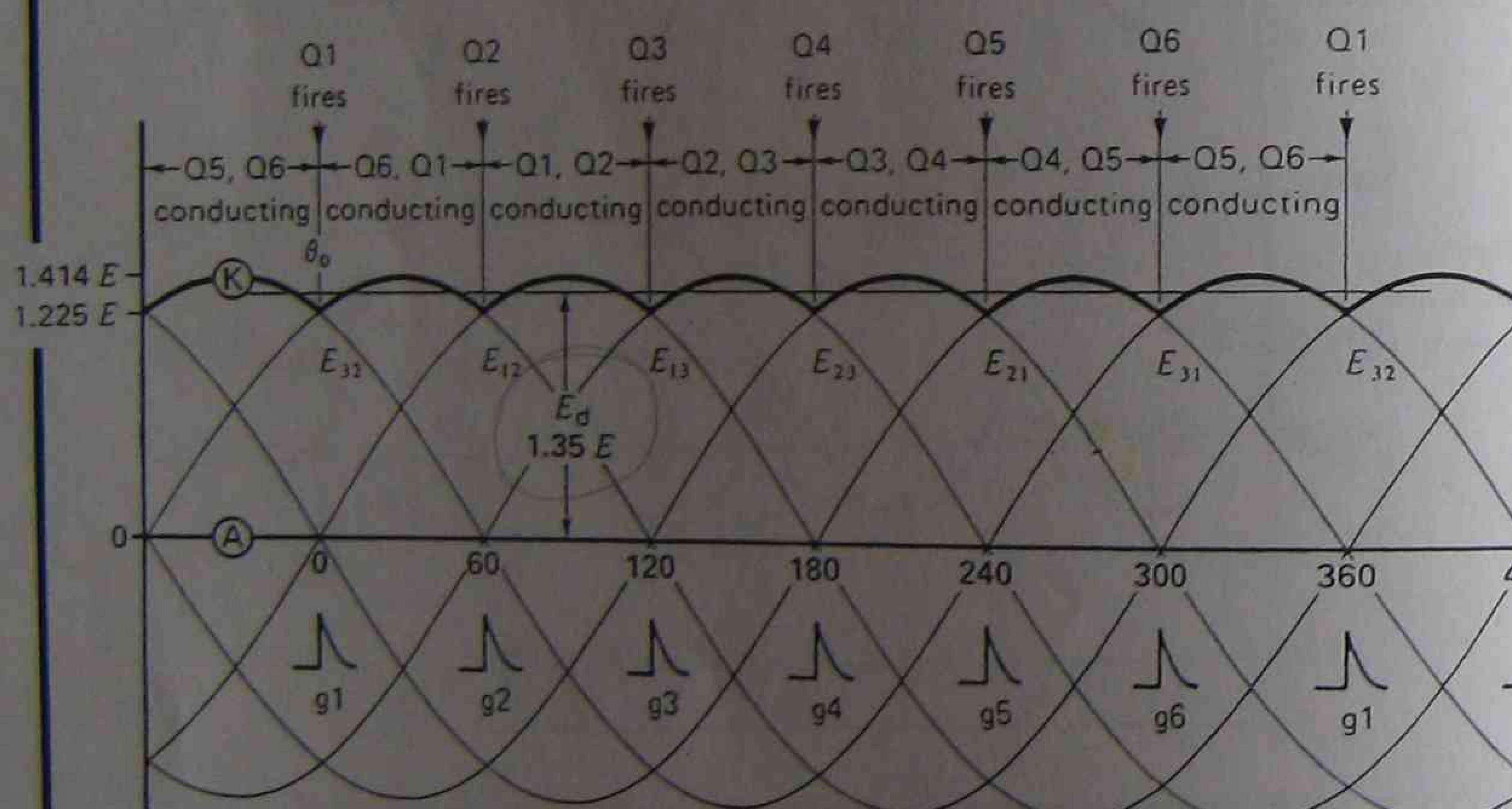


Figure 21-51a
Delay angle: ze

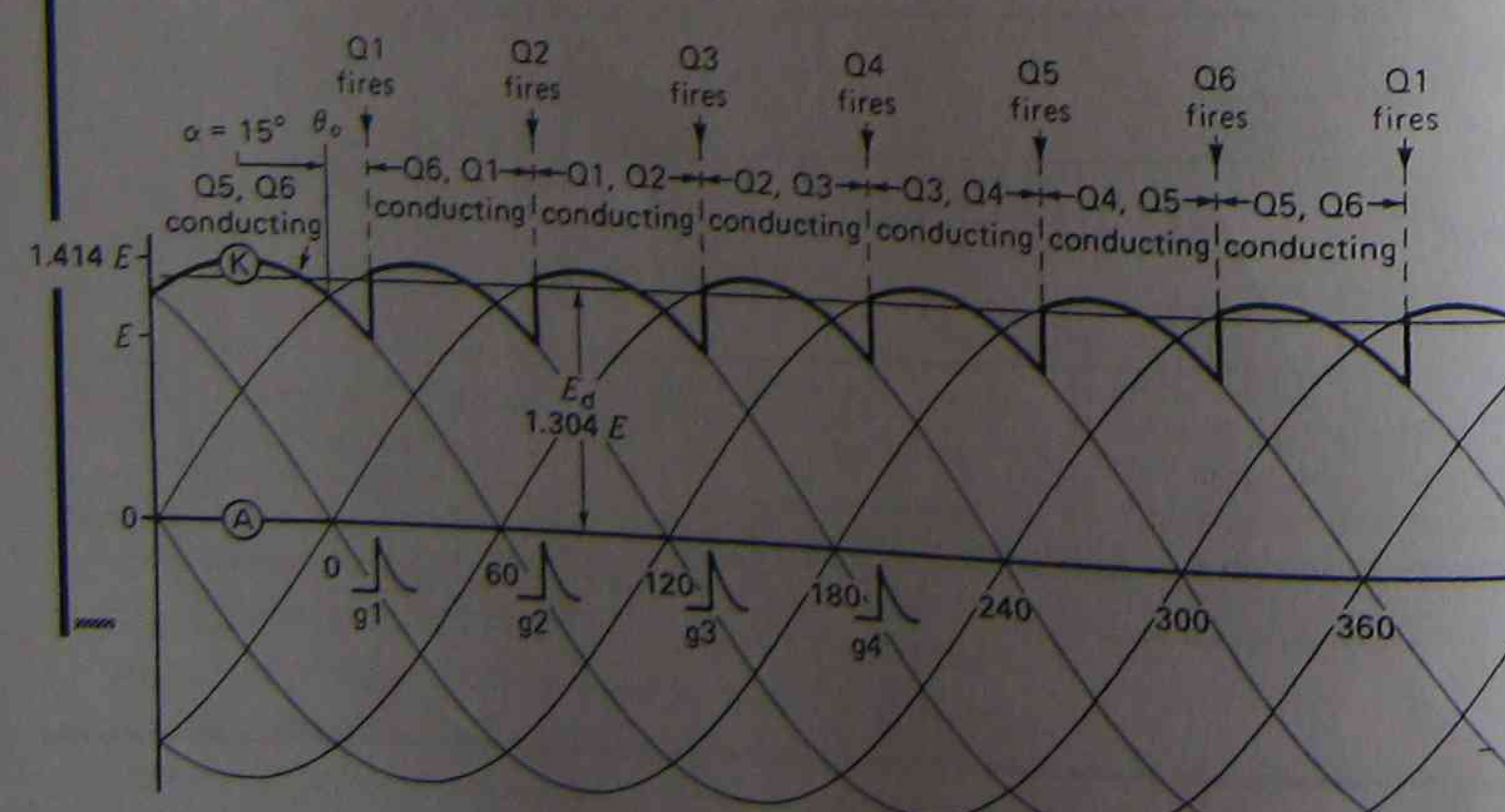


Figure 21-51b
Delay angle: 15°

A.C. Motor Control.
Topic -

21.28 Delayed triggering – rectifier mode

Let us now delay all triggering pulses by an angle α of 15° (Fig. 21-51b). Current I_d, instead of switching over to Q1 at θ_0, will continue to flow in Q5 until gate pulse g1 triggers Q1. Commutation occurs, and the potential of point K jumps from line 3 to line 1. A similar switching action takes place (but at later times) for the other thyristors. The resulting choppy waveshape between terminals K and A is shown in Fig. 21-51b.

Note that the triggering delay does not shorten the conduction period; each thyristor still conducts for a full 120° and each voltage segment has a duration of 60 degrees. Furthermore, the current remains constant and ripple-free, owing to the presence of the big inductor. The level of point K follows the tops of the individual sine waves, but the average voltage E_d, between K and A, is obviously smaller than before. We can prove that it is given by:

$$E_d = 1.35E\cos\alpha \qquad (21\text{-}17)$$

where

E_d = dc voltage produced by the 3-phase, 6-pulse converter [V]

E = effective value of the ac line-to-line voltage [V] — Vrms

α = firing angle [°]

According to Eq. 21-17, E_d becomes smaller and smaller as α increases. However, if E_d becomes equal to or less than E_0, the load current ceases to flow. Ordinarily, the current would reverse when E_d is smaller than E_0. However, this is impossible, because the SCRs can only conduct in the forward direction.

Figures 21-51c and 21-51d show the waveform between K and A for α = 45° and 75°, respectively. The ac component in E_{KA} is now very large, compared to the dc component.

Example 21-9.

The 3-phase converter of Fig. 21-50 is connected to a 3-phase 480 V, 60 Hz source. The load consists of a 500 V dc source having an internal resistance of 2 Ω. Calculate the power supplied to the load for triggering delays of a. 15°, b. 75°.

Solution:

③ Active Power $P_1 = S_1 \cos\phi$ KW
$P_1 = 1.35 V_{rms} I_D \cos\phi$ KW

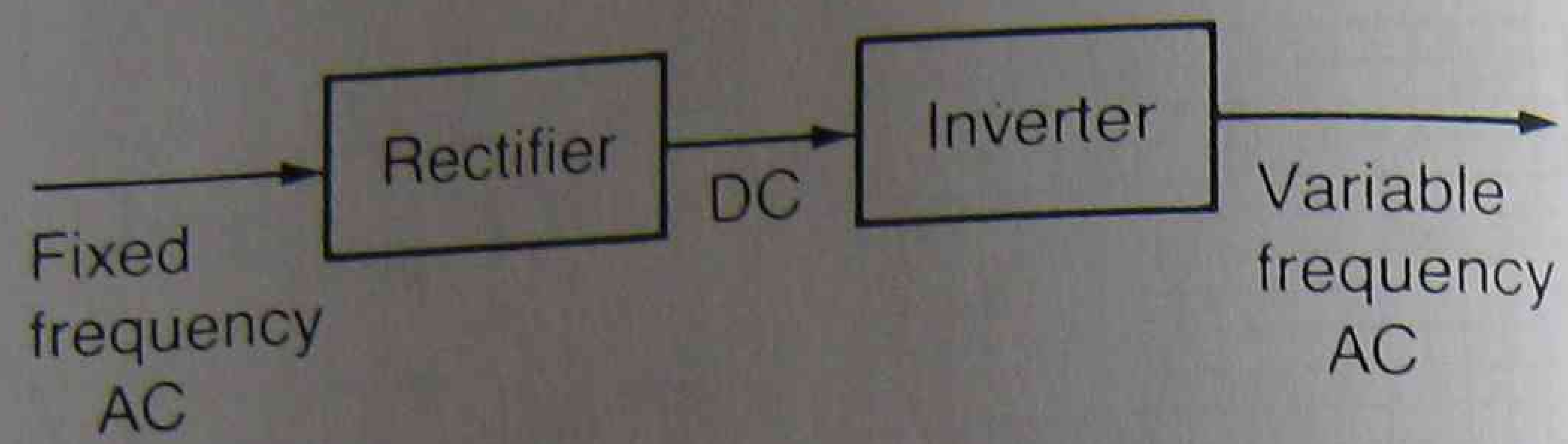
② Apparent Power $S_1 = \sqrt{3} V_{rms} I_1$ KVA
$= \sqrt{3} V_{rms}\, 0.78 I_D$ KVA
$= 1.35 V_{rms} I_D$

④ Reactive Power $Q = S_1 \sin\phi$ kVAr

① $I_{1\,rms} = \sqrt{3}\frac{\sqrt{2}}{\pi} I_D = 0.78 I_D$ amps

I_D = DC Current.

Delay angle	converter behaviour
α = 0°	Resistive load
0° < α < 90°	Resistive/Inductive load
α = 90°	Pure Inductive load
α > 90°	Source from Ind load



In the inverter section, three approaches are used to convert DC to adjustable-frequency AC. First, the *variable-voltage inverter (VVI)* takes input power in the form of an adjustable DC source. This source presets the input DC voltage to provide the required output voltage amplitude from the inverter. In one type of VVI, a phase-controlled bridge rectifies the incoming AC voltage. The volts/Hz ratio is kept constant by changing the amplitude of the rectified DC as the frequency is changed. A second type of VVI replaces the phase-controlled rectifier bridge with a diode bridge and a DC regulator or chopper. This system, therefore, has a rectifier that is divided into two parts: the diode bridge, which converts fixed frequency AC to a constant voltage DC, and the regulator or chopper, which changes the constant DC voltage to a variable DC voltage. Normally, the VVI drives lack the ability to apply regenerative braking. Of the types of inverter drives, the VVI drives are the simplest in construction, used in industry for applications up to 400 HP.

The *current-source inverter (CSI)* takes input power for an adjustable current source, not a voltage source, as in the VVI. Except for the current source, the CSI drive is similar in construction to the VVI. The CSI drive, however, can apply regenerative braking to a motor.

The *pulse-width modulated (PWM) inverter* takes voltage from a fixed voltage source. The peak output voltage applied to the motor is, therefore, constant. The average value of the output voltage wave form is controlled by changing the width of the zero voltage interval in the output wave form.

11–2.3 Variable-Voltage, Variable-Frequency Control

This type of induction motor speed control uses a circuit called an inverter. The purpose of the inverter is to control the speed of the motor by adjusting the frequency. To produce a constant torque for the motor, the inverter drive must keep a constant V/Hz ratio. The way in which the inverter adjusts the frequency and voltage is determined by the particular type of inverter used. The variable-voltage, variable-frequency drive will be discussed first.

The variable-voltage, variable-frequency inverter is also known as a voltage-fed inverter or, simply, as a variable-voltage inverter (VVI). The VVI can be further broken down into two types: six-step (quasi-square wave inverter) and pulse-width modulated inverters.

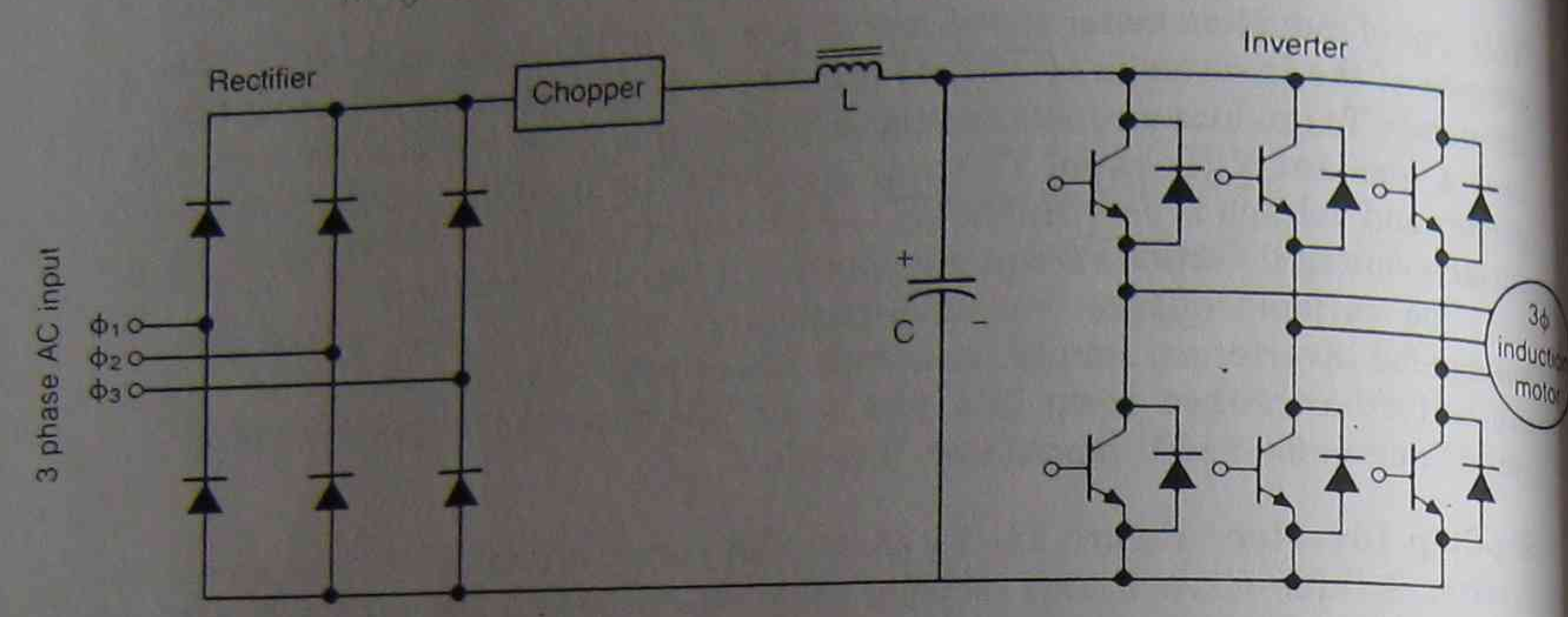
Six-Step Inverter Figure 11–7a shows the power circuit of a three-phase inverter. A three-phase bridge rectifier converts AC to DC. The output voltage of the rectifier section is varied by a DC chopper. A thyristor chopper is preferable to a transistor chopper, which must use several transistors connected in parallel. Regardless of the type of chopper used, the chopper varies the constant DC voltage from the rectifier, which is then applied to the inverter. This type of inverter is called voltage fed because a large filter capacitor provides a stiff voltage supply to the inverter.

The inverter output voltage wave forms are not affected by the nature of the load. Figure 11–7b shows another way to vary the input voltage. In this method, the uncontrolled diode rectifier and the chopper regulator are replaced by a phase-controlled bridge rectifier. The principle of the variable-voltage, variable-frequency speed control method is shown in Figures 11–8 and 11–9.

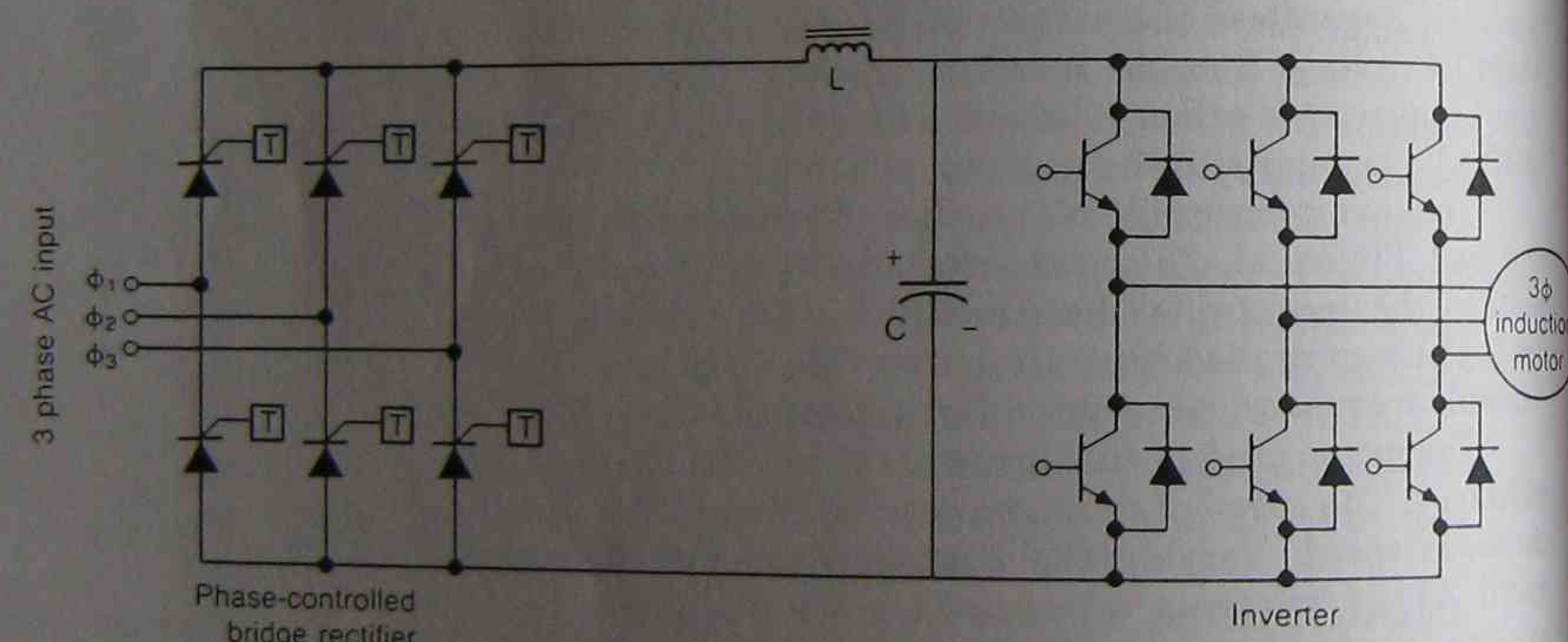
The motor used in this drive has a low slip characteristic that improves efficiency. The speed of the motor can be changed by simply varying its synchronous speed. Varying the inverter frequency changes the synchronous speed. As the frequency is increased, however, the machine air gap *flux* falls, causing low developed torque capability. The air gap flux can be maintained constant, as in a DC shunt motor, if the voltage is varied with frequency so that the ratio remains constant.

Figure 11–8 shows the desired voltage-frequency relationship of the motor. Below the base frequency, the air gap flux is kept constant by the constant V/Hz ratio, which keeps the torque constant. At a very low frequency, the stator resistance is greater than the leakage inductance. To counter this effect, additional voltage is applied. At the base frequency, the input voltage regulator establishes full-motor voltage. Beyond this point, as frequency increases, the torque decreases because of loss of air gap flux. From this point on, the machine operates in a constant horsepower mode, as shown in Figure 11–9. In the constant horsepower mode, each torque-speed curve corresponds to a particular voltage and frequency combination at the machine terminal.

VVI



a. Six-step inverter with a conventional rectifier, chopper, and inverter



b. Six-step inverter with phase-controlled rectifier and inverter

FIGURE 11–7 Three-phase inverter

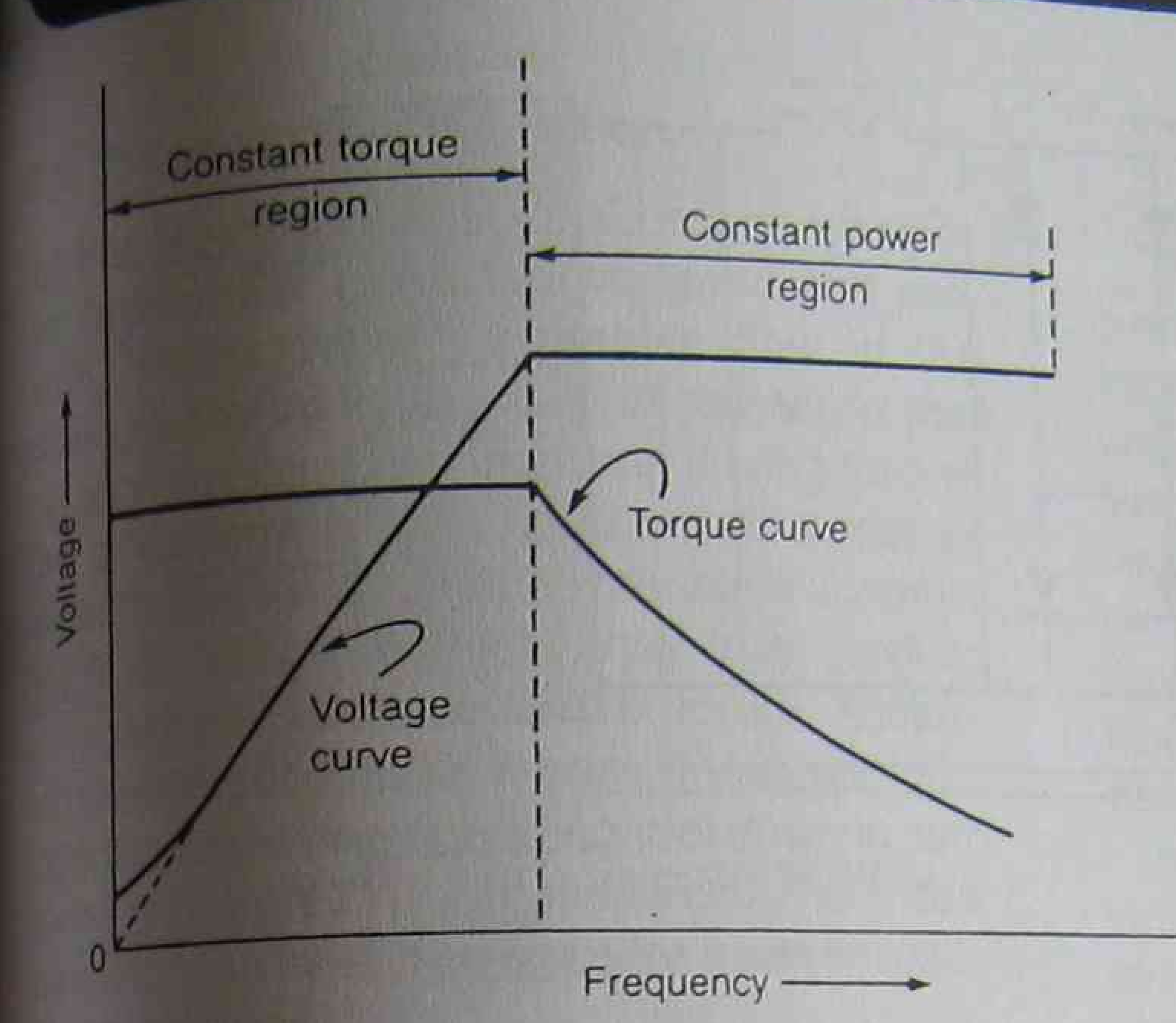


FIGURE 11–8 Voltage-frequency curve of induction motor

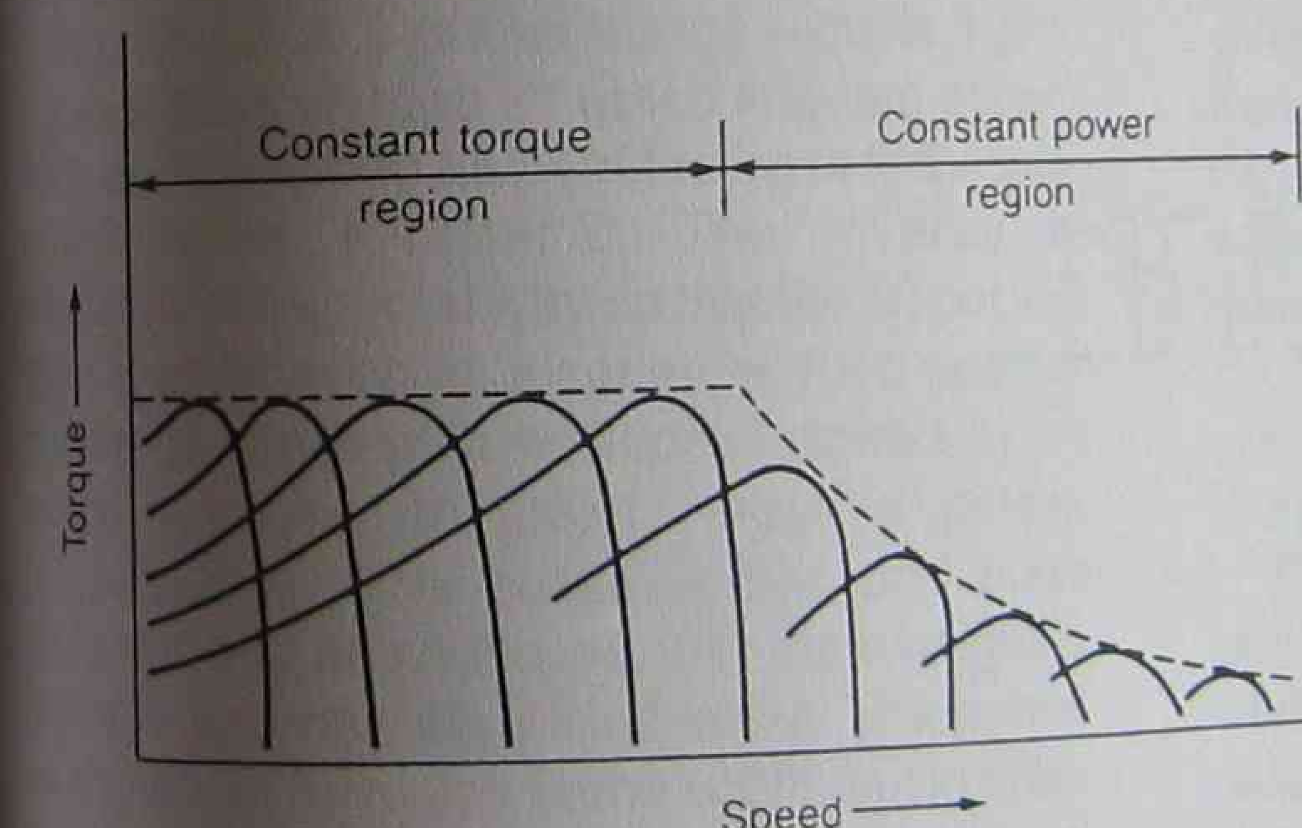


FIGURE 11–9 Torque-speed curves of induction motor with variable-voltage, variable-frequency power supply

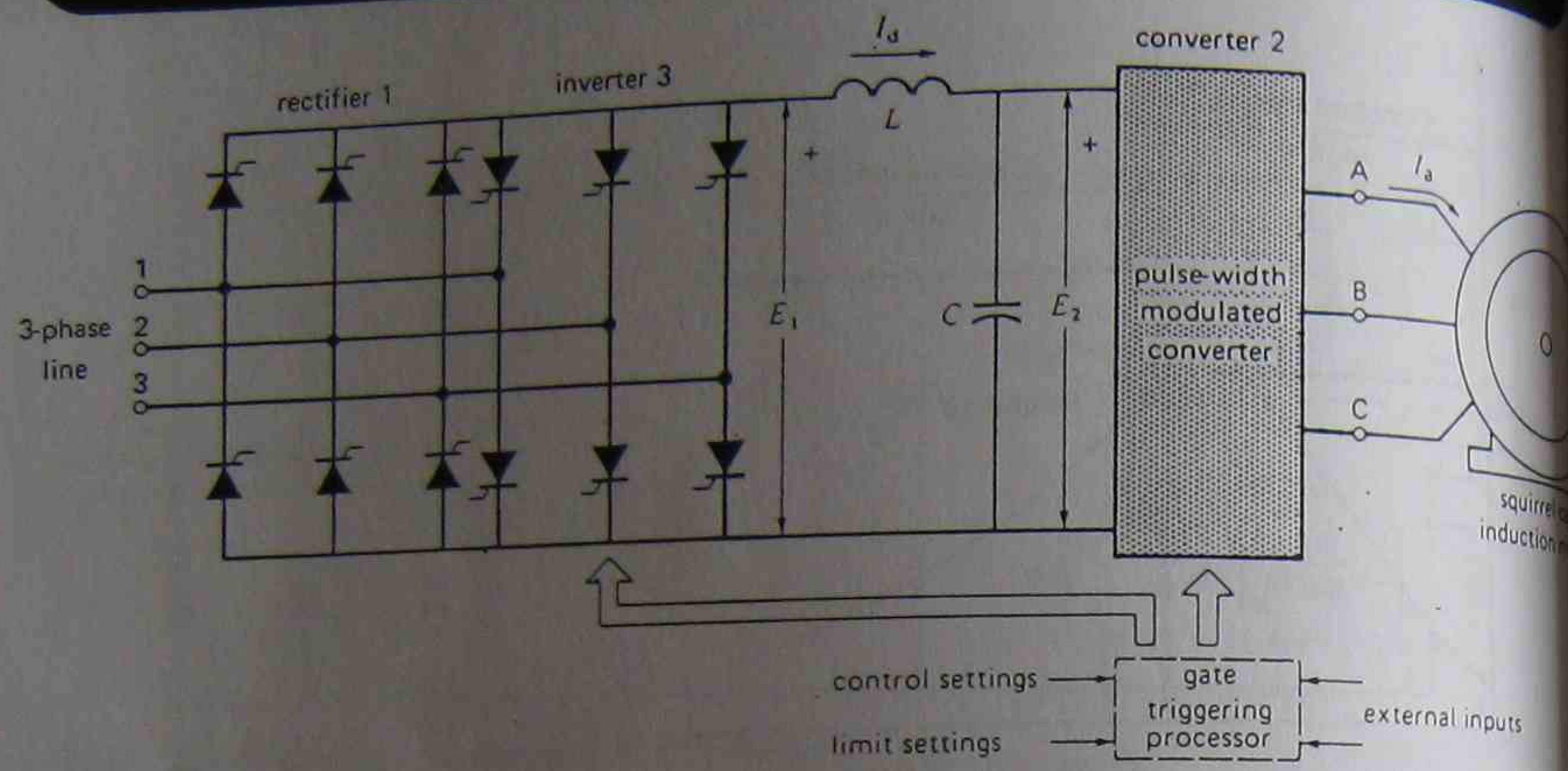


Figure 23-19
Speed control by pulse width modulation.

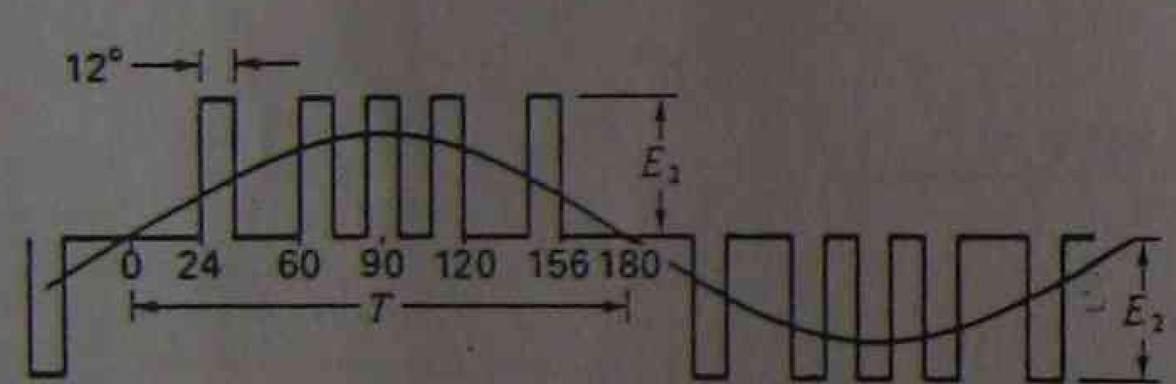


Figure 23-20a
Voltage waveform across one phase.

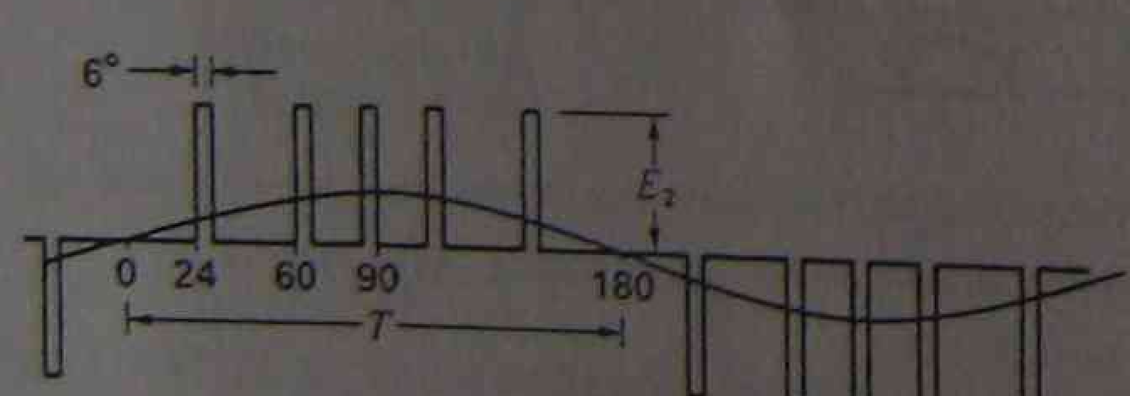


Figure 23-20b
Waveform yielding the same frequency but half the voltage.

23.9 Pulse width modulation

The frequency converters discussed so far create substantial harmonic voltages and currents. When these harmonics flow in the windings, they produce torque pulsations that are superimposed on the main driving torque. The pulsations are damped out at moderate and at high speeds owing to mechanical inertia. However, at low speeds, they may produce considerable vibration. Such torque fluctuations are unacceptable in some industrial applications, where fine speed control down to zero speed is required. Under these circumstances, the motor can be driven by *pulse width modulation* techniques.

To understand the technique, consider the voltage-fed frequency converter system shown in Fig. 23-19. A 3-phase bridge rectifier 1 produces a fixed voltage E_1 which appears essentially undiminished as E_2 at the input to the self-commutated inverter 2. The inverter is triggered in a special way so that the output voltage is composed of a series of short positive pulses of constant amplitude, followed by an equal number of short negative pulses (Fig. 23-20a). The pulse widths and pulse spacings are arranged so that their weighted average approaches a sine wave. The pulses as shown all have the same width, but in practice, the ones near the middle of the sine wave are made broader than those near the edges. By increasing the number of pulses per half cycle, we can make the output frequency as low as we please. Thus, to reduce the output frequency of Fig. 23-20a by a factor of 10, we increase the pulses per half-cycle from 5 to 50.

The pulse widths and pulse spacings are specially designed so as to eliminate the low-frequency voltage harmonics, such as the 3rd, 5th, and 7th harmonics. The higher harmonics, such as the 17th, 19th, etc., are unimportant because they are damped out, both mechanically and electrically. Such pulse width modulation produces output currents having very low harmonic distorsion. Consequently, torque vibrations at low speeds are greatly reduced.

In some cases, the output voltage has to be reduced while maintaining the same output frequency. This is done by reducing all the pulse widths in proportion to the desired reduction in output voltage. Thus, in Fig. 23-20b, the pulses are half as wide as in Fig. 23-20a, yielding an output voltage half as great, but having the same frequency. We can therefore vary both the output frequency and output voltage using a fixed dc input voltage. As a result, a simple diode bridge rectifier can be used to supply the fixed dc link voltage. The power factor of the 3-phase supply line is therefore high.

Regenerative braking can be achieved, but during such power reversal, current I_d reverses while the polarity of E_2 remains the same. Consequently, an extra inverter 3 has to be placed in reverse parallel with rectifier 1 in order to feed power back to the line (Fig. 23-19). Rectifier 1 is automatically blocked while inverter 3 is in operation, and vice versa.

Pulse-width modulation is effected by computer control of the gate triggering.

A.C. Motor Control.

Topic -

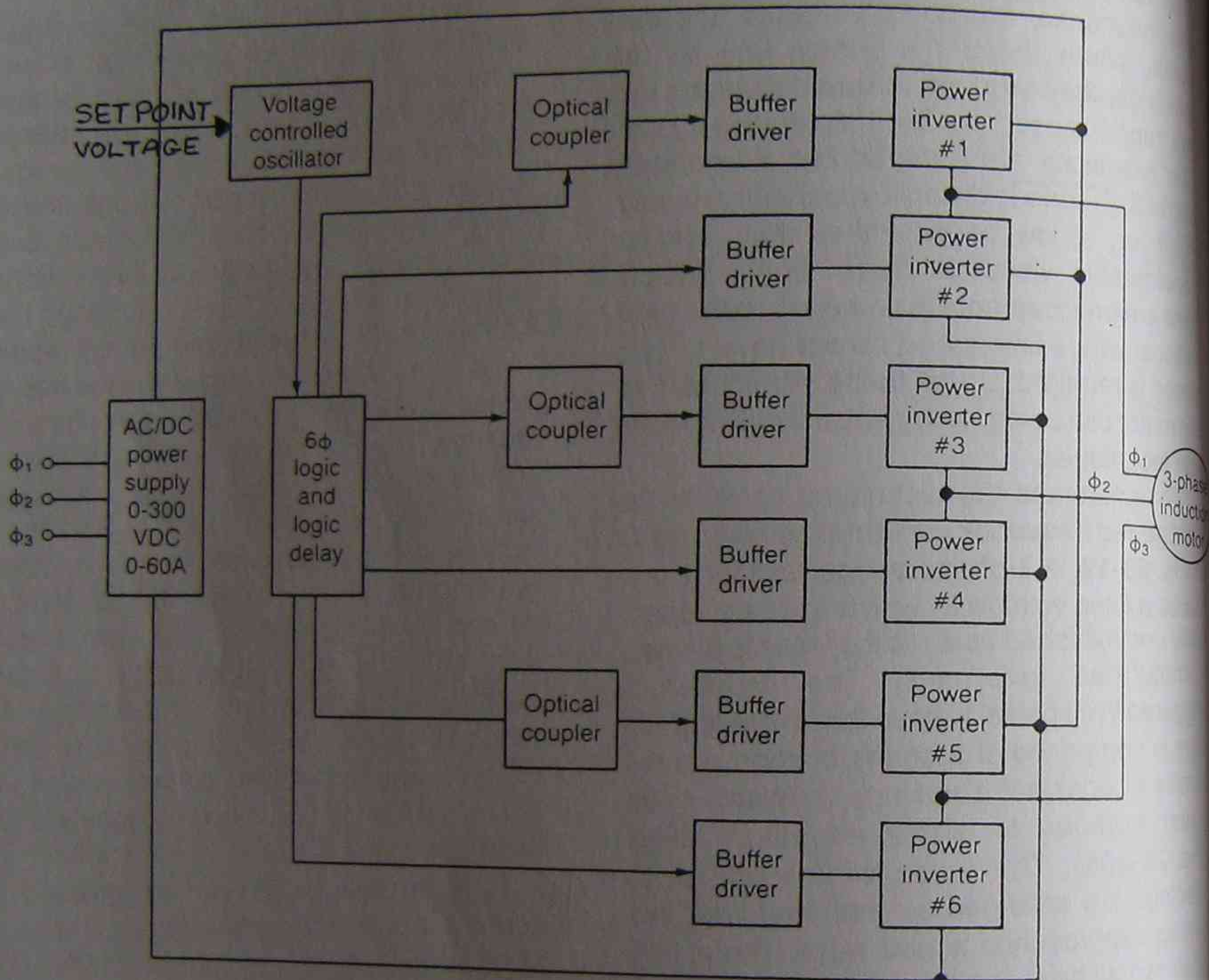


FIGURE 11–10 AC motor speed control—block diagram

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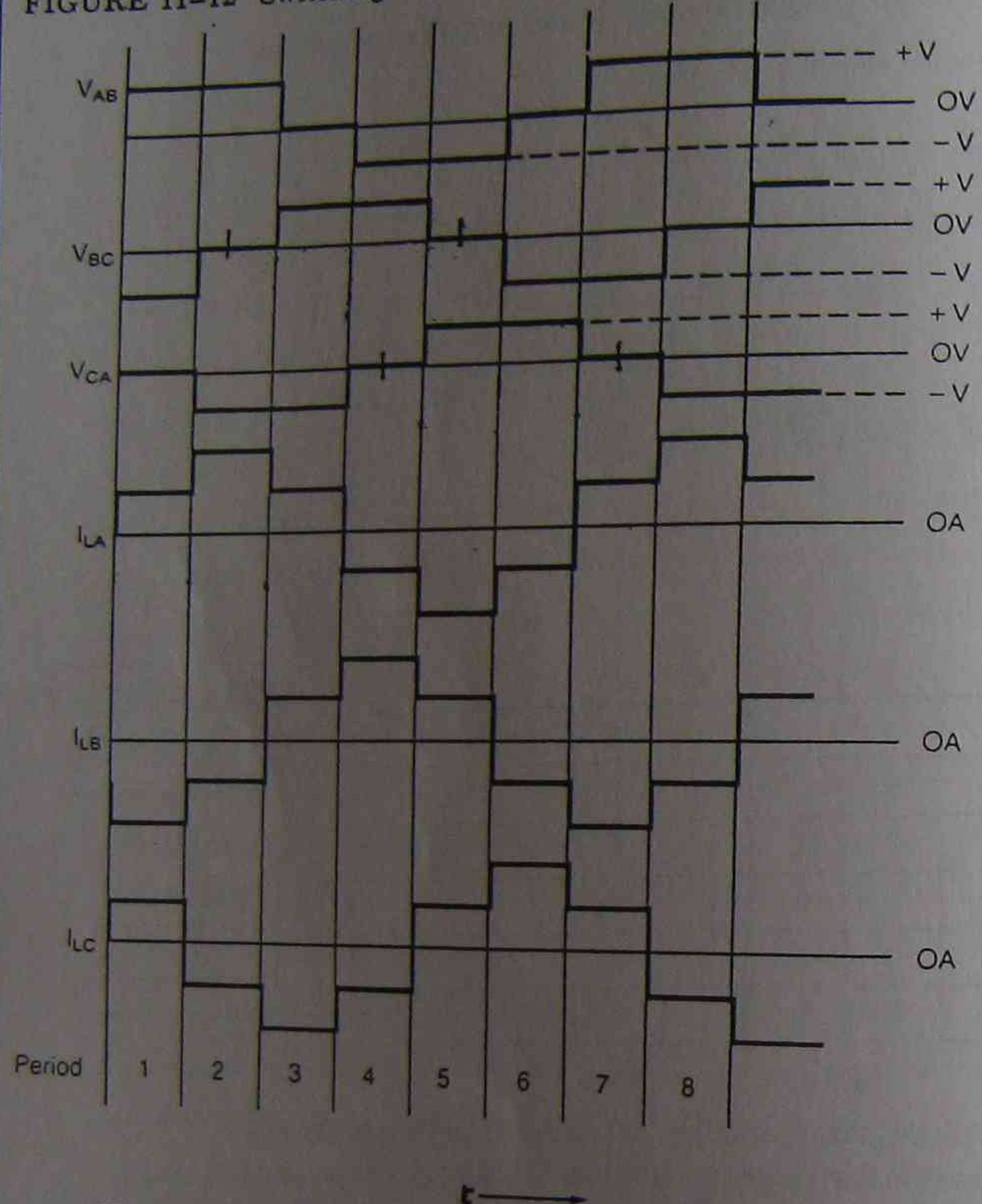
FIGURE 11–12 Switching sequence synchrogram



Each of the voltages applied to the three phases is displaced 120° from each other, as shown in Figure 11–12. This figure shows the line-to-line voltages, V_{AB}, V_{BC} and V_{CA}. These voltages were found by adding the voltages algebraically. During periods *1* and *2*, the voltage from *A* to *B* = +*V*, since *B* is at the –*V* potential. During period *3*, the voltage *A* to *B* is 0 V, since both *A* and *B* are at +V. In this way, a six-step wave form is achieved.

The output AC voltage can be changed by varying the input DC voltage. The output frequency can be varied by varying the switching frequency of the transistors (*S1* through *S6*). Typically, the maximum frequency for motor speed control using a six-step inverter is 200 Hz.

A.C. Motor Control.
Topic -

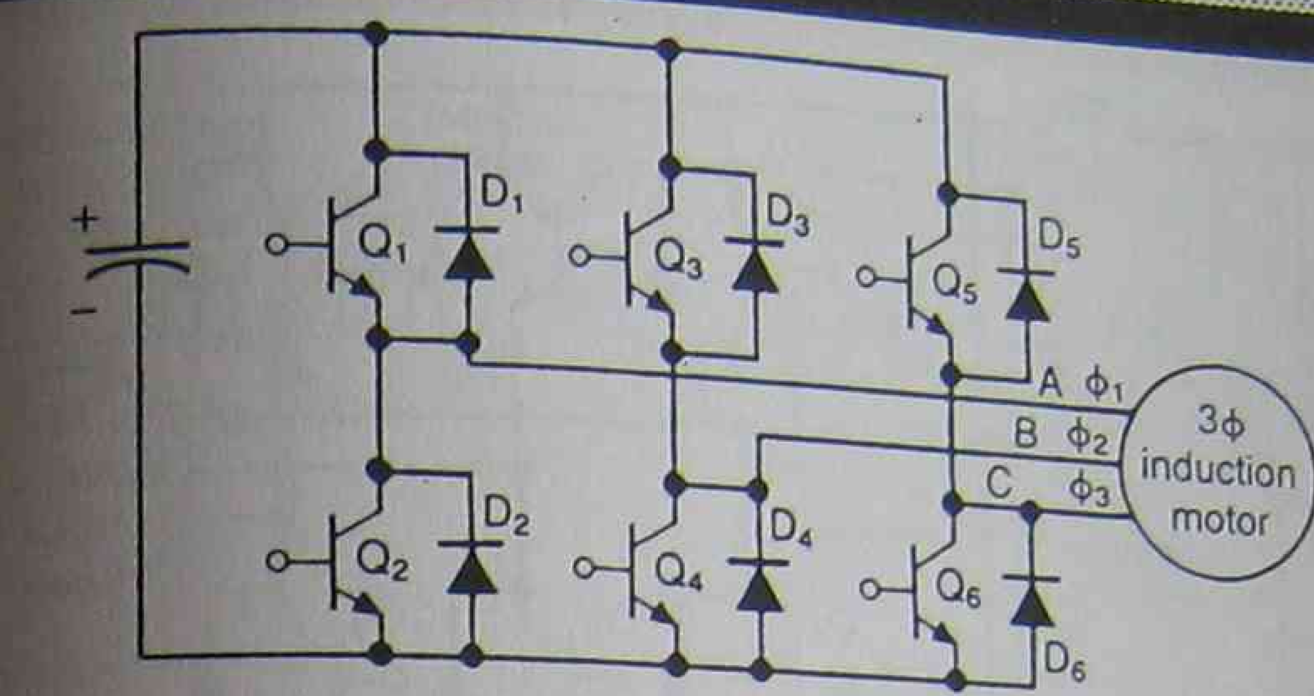


FIGURE 11–13 Six-step inverter using transistors as switches

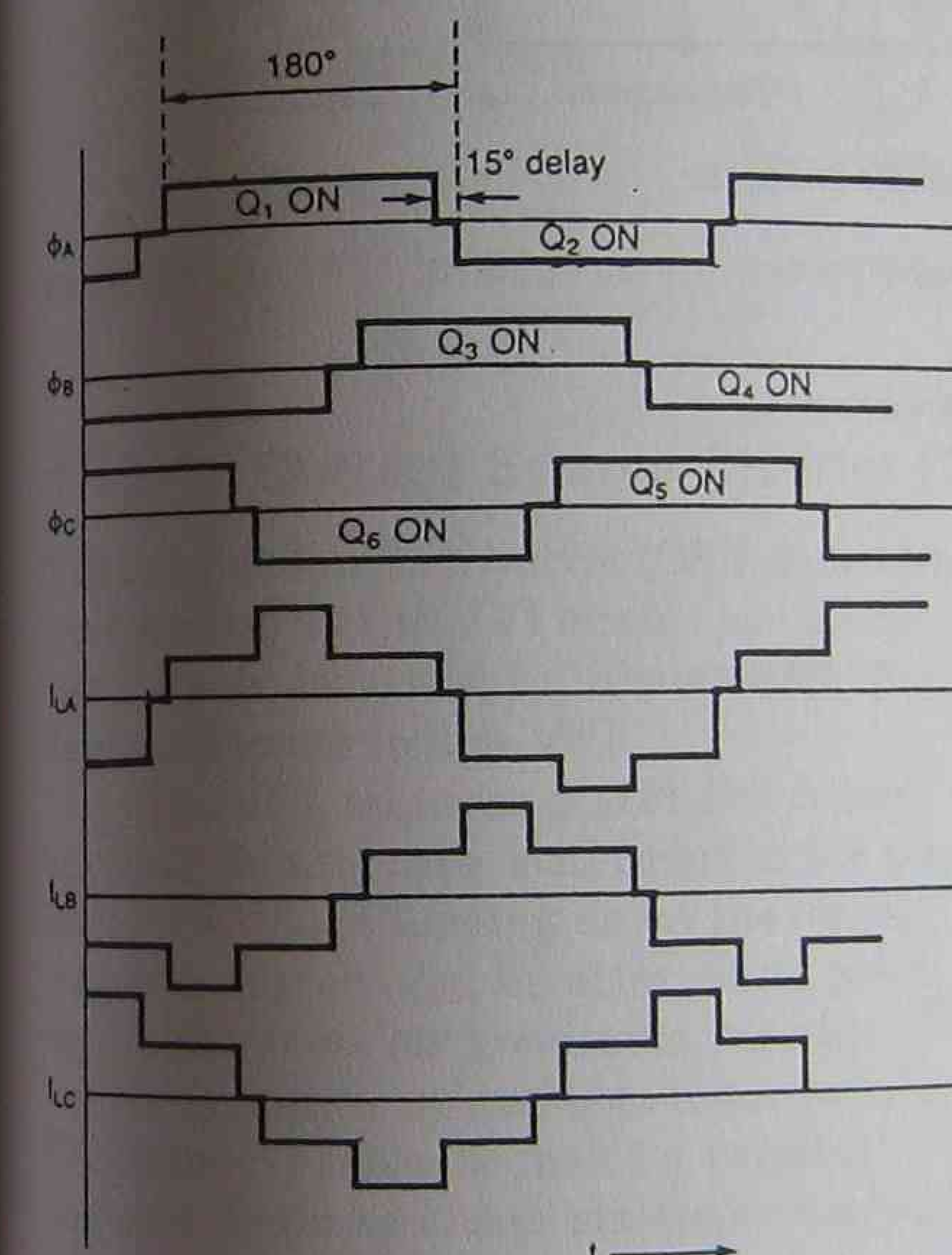


FIGURE 11–14 Six-step inverter synchrogram

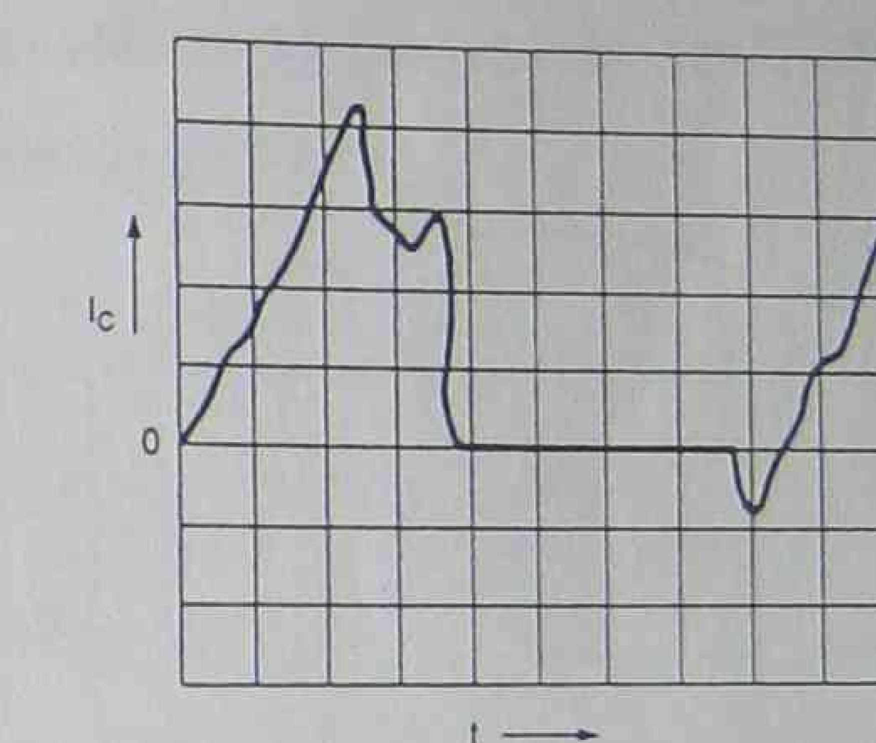


FIGURE 11–15 Typical collector current with motor load

Figure 11–12 shows that at any time three switches (transistors) are [con]ducting, one is conducting in each leg of the bridge, and the successive legs [ar]e switched with delays of 210°. As shown in Figures 11–13 and 11–14, tran[sis]tors *Q1* through *Q6* theoretically conduct for 180°.

However, in a practical situation, it is necessary to provide some time [de]lay (typically 10° to 15°) between the positive-to-negative transition period [o]f the phase current. This time delay enables the complementary transistor [(Q_1] is complement to Q_2, etc.) to turn off before its opposite member turns on. [Th]is action prevents cross-conduction and eventual destruction of the power [tra]nsistors. Therefore, the maximum conduction time will be 165° out of a 360° [pe]riod. The diodes connected in parallel with each transistor conduct current [wh]en the transistor is turned off, represented by –Ic in Figure 11–15.

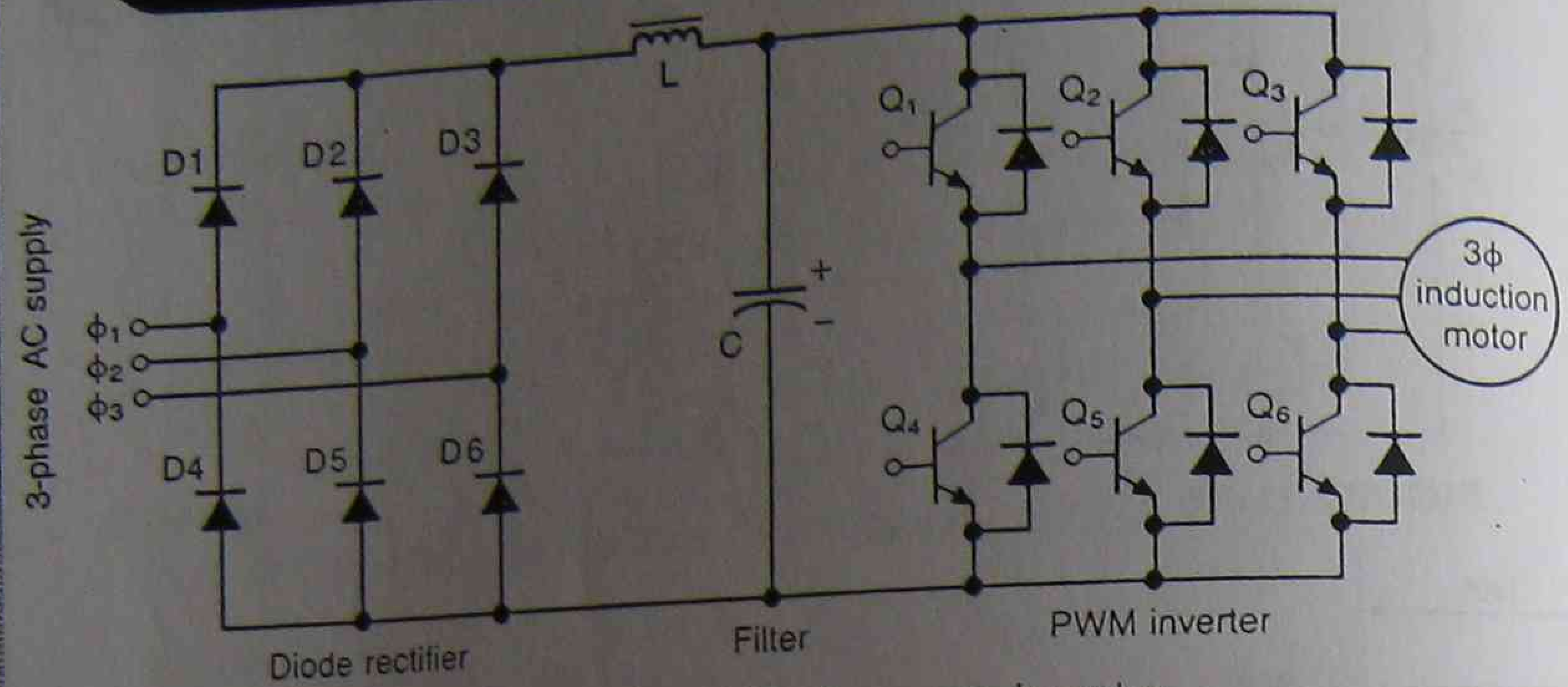


FIGURE 11–17 Variable-voltage, variable-frequency inverter

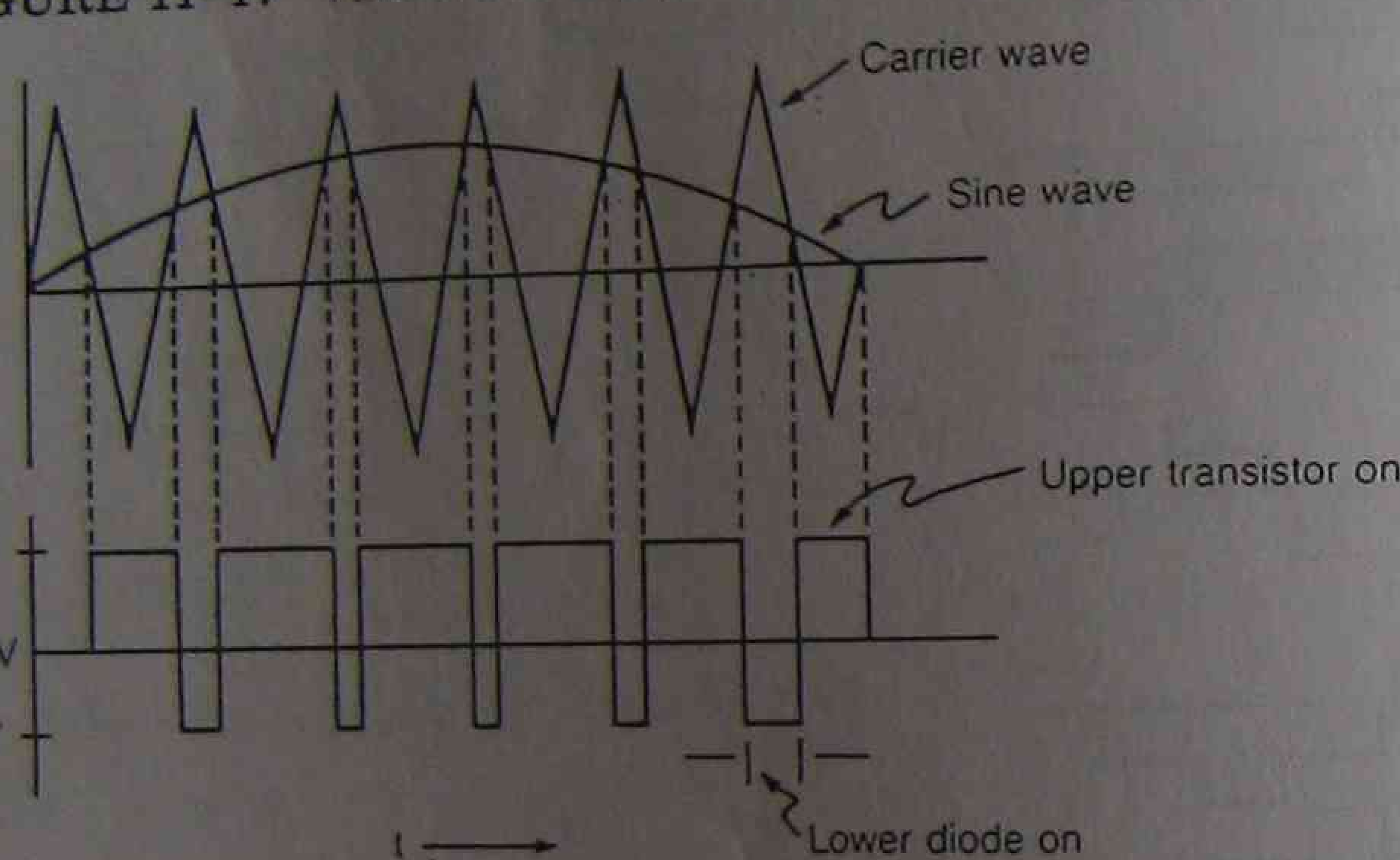


FIGURE 11–18 Pulse-width modulation by sine wave

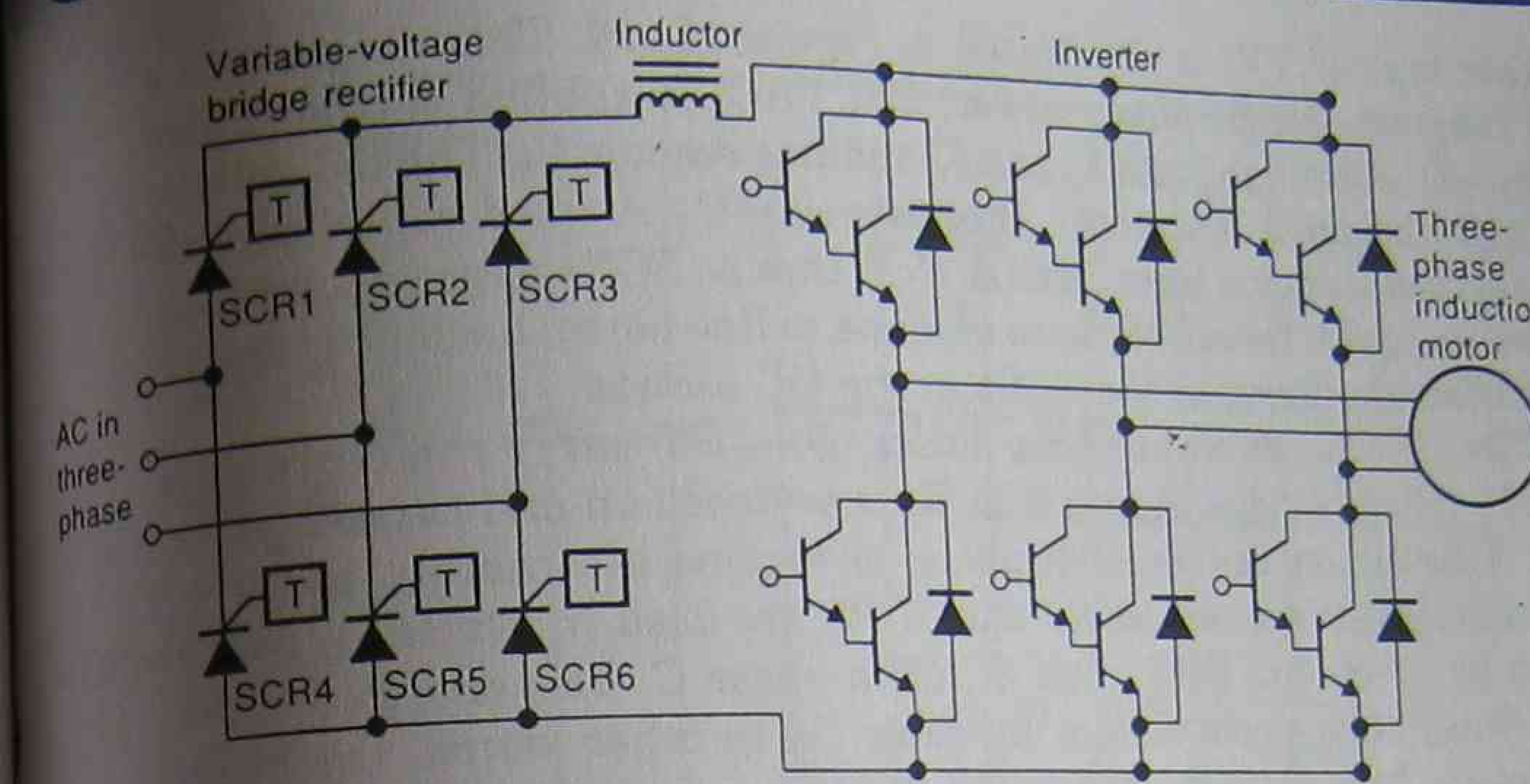


FIGURE 11–19 Variable-current, variable-frequency motor drive

11–2.4 Current Source Inverter (CSI)

The current source inverter (CSI), sometimes called the current-fed inverter, is very similar to the VVI circuit just discussed. Its name suggests that current, not voltage, is varied in this inverter. A large inductor is used in place of the large capacitor in the VVI.

The CSI requires a *stiff* DC current source as opposed to a voltage-fed inverter. In this case, stiff refers to the capability to provide a large amount of current without loading down the circuit. Figure 11–19 shows the power circuit of a current-fed inverter using power Darlingtons as switches. A phase-controlled rectifier generates variable DC, which is converted to a current source by connecting a large inductor in series. A diode rectifier, followed by a DC chopper, can also make a variable DC source. The mode of control of the inverter could be either six-stepped or pulse-width modulated, similar to that of a voltage-fed inverter.

Another type of VVI is illustrated in Figure 11–16. This diagram is a simplified diagram. Single-phase power, 220 VAC, is applied to the bridge rectifier (D_9—D_{12}) through fuses F_1 and F_2 and line reactor L_1. The DC voltage produced by the bridge is filtered by filter capacitor C_4. A fixed value, filtered DC voltage is then found on lines *1* and *5*. Note that no SCRs appear across the AC line. This design is, therefore, more immune to line noise, hash, and spikes that might affect the firing of the SCRs in the DC section.

Six SCRs (*SCR1—SCR6*) and six diodes (*D1—D6*) carry the current in the adjustable voltage bridge. A pair of SCRs is switched on and turned off for each phase. This action causes each phase to become alternately positive-negative-positive-negative, etc. *SCR1* and *SCR2* are used in phase *A*, *SCR3* and *SCR4* in phase *B*, and *SCR4* and *SCR5* in phase *C*. The energy for the adjustable voltage bridge comes from capacitor C_3. In other words, the SCRs are drawing power from C_3 to run the motor, and they are continually trying to discharge C_3. The capacitor C_3 is charged by the fixed voltage bridge.

Each pair of SCRs controlling each phase is turned on and commutated off in the proper timing sequence to supply three-phase power to the motor by the main control circuit board (not shown in the simplified diagram). The faster the switching on and commutating off, the higher the frequency.

The six SCRs in the fixed voltage bridge (*SCR11—SCR16*) operate in parallel with their equivalents in the adjustable voltage bridge (*SCR1—SCR6*). The purpose of the fixed voltage bridge is to furnish energy to C_3 as the motor load uses it and to commute (turn off) the SCRs in the adjustable voltage bridge.

When an SCR in the adjustable voltage bridge, for example *SCR1*, is turned on, its equivalent in the fixed voltage bridge (*SCR11*) can be turned on at 10 kHz rate. It will be turned on for one pulse any time C_3 voltage is too low. When it is turned on for a pulse, energy comes from the DC line (lines *1* and *5*) through X_1 or X_2. Some of this energy goes to the motor, and the excess goes through the back diode (*D1—D6*) and helps recharge C_3. If C_3 voltage continues to be too low, another pulse of energy will be called for and once again the SCR in the fixed voltage bridge will be turned on. Up to 10,000 pulses of energy per second can be obtained from each SCR in the fixed voltage bridge in this manner.

To commutate off an SCR in the adjustable voltage bridge, for example *SCR1*, its gate is turned off. Then its mate in the fixed voltage bridge (*SCR11*) is turned on for a pulse, causing current to flow. Some current flows to the motor; the excess flows through the back diode *D1*. This action shunts *SCR1*, causing it to stop conducting.

The SCRs in the fixed voltage bridge turn themselves off naturally after each pulse because they conduct into a tuned circuit. The voltage rises at the end of the pulse to block any further current flow.

A.C. Motor Control.
Topic -

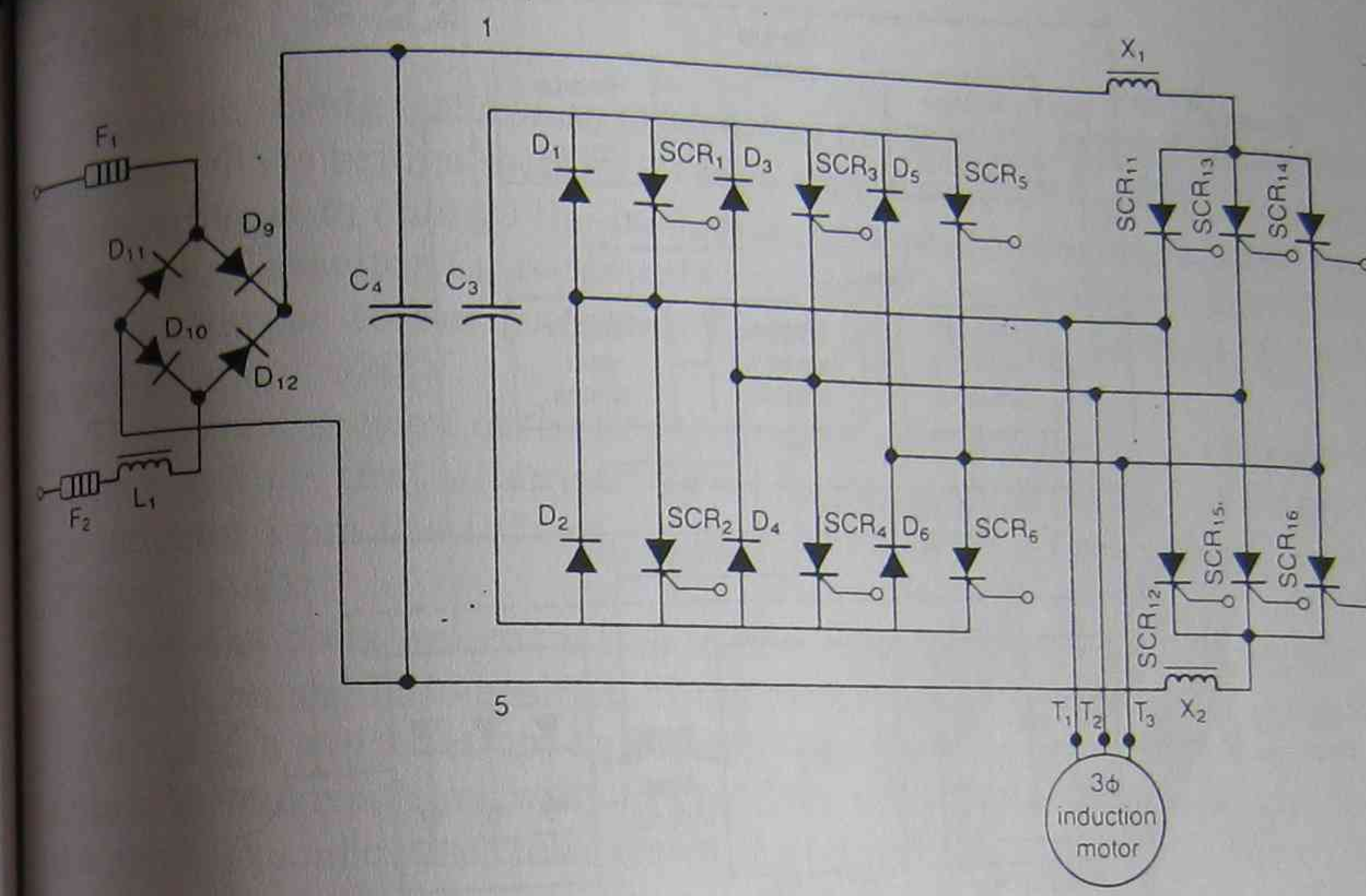
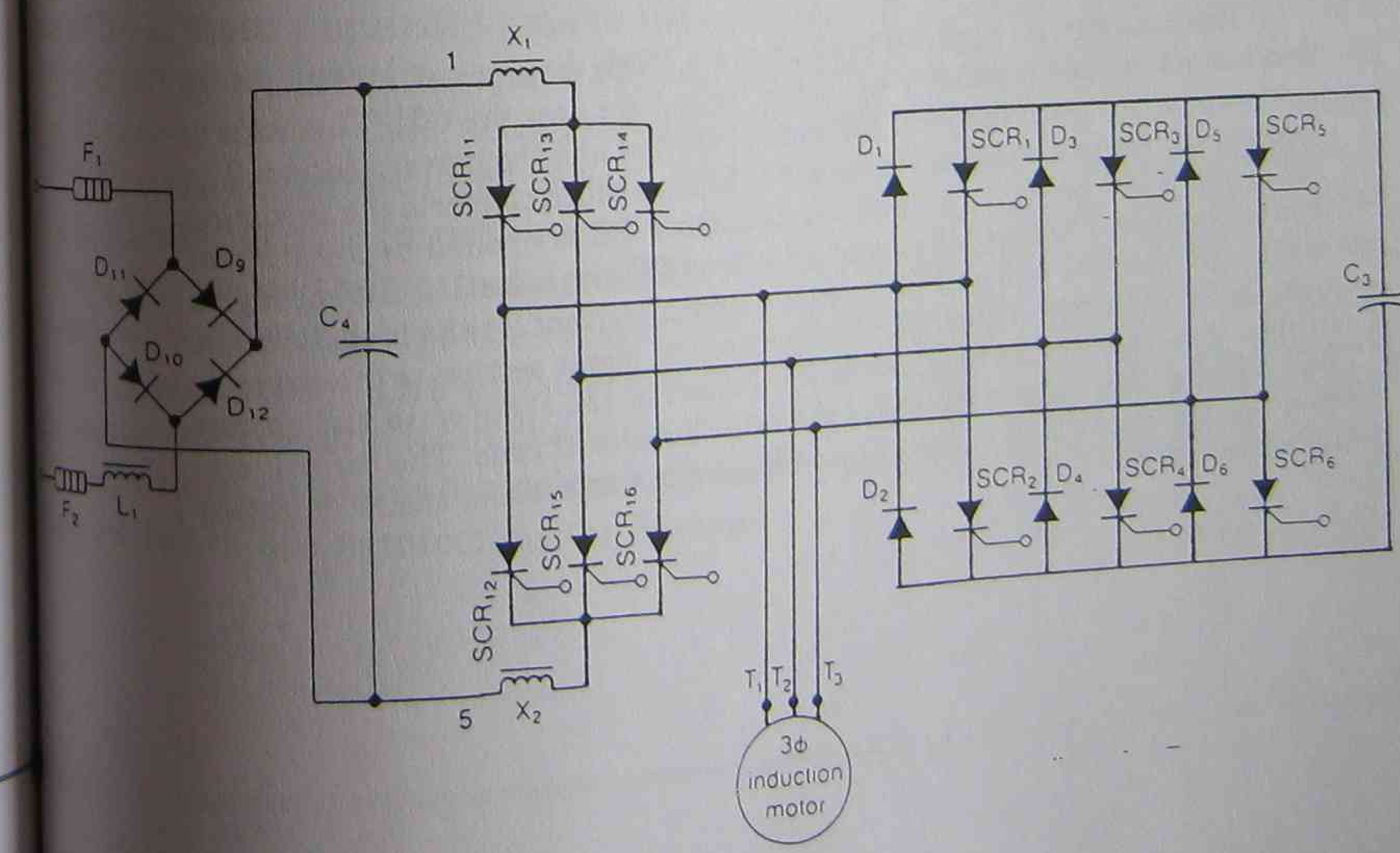


FIGURE 11–16 VVI AC motor drive using SCRs as switches



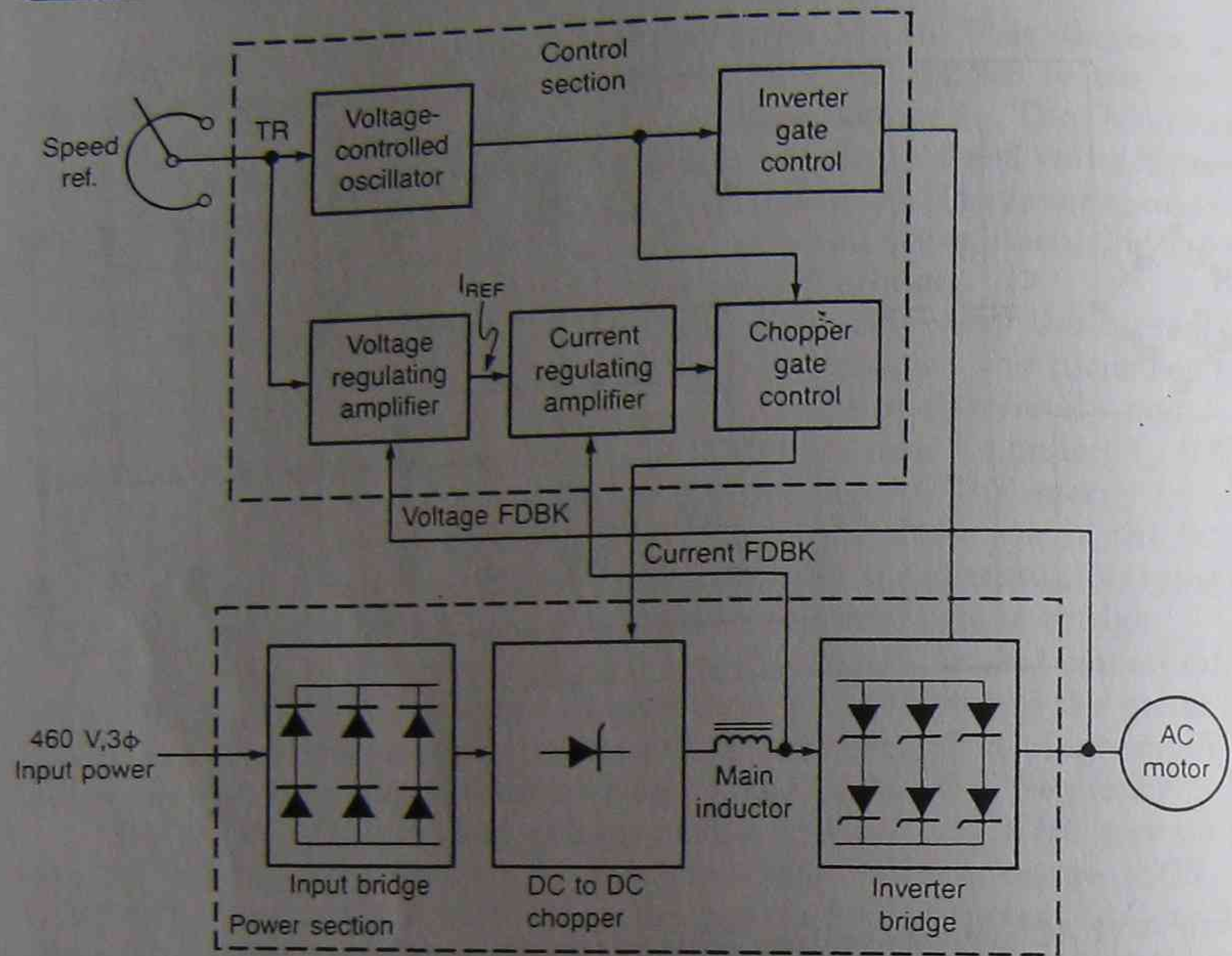


FIGURE 11–20 Graham 1580 CSI AC motor speed control (courtesy of Graham Co.)

The diagram in Figure 11–20 shows a block diagram of a Model 1580 Graham adjustable frequency AC drive. This drive uses the CSI. The drive is made up of two main sections: the control section and the power section. The first part of the power section is the input bridge, which converts the incoming three-phase AC power to a fixed DC. The fixed DC is applied to the current source chopper. The chopper converts the fixed DC to a pulsating DC through a large inductor. The inductor becomes a source of current for the load, which is usually an induction motor. The last part of the power section is the inverter bridge. The inverter bridge directs the output of the chopper to the correct phase of the three-phase motor for the right amount of time. The control section has the regulating circuitry for voltage and current and the SCR gating logic circuitry.

FIG 11-21 & 22

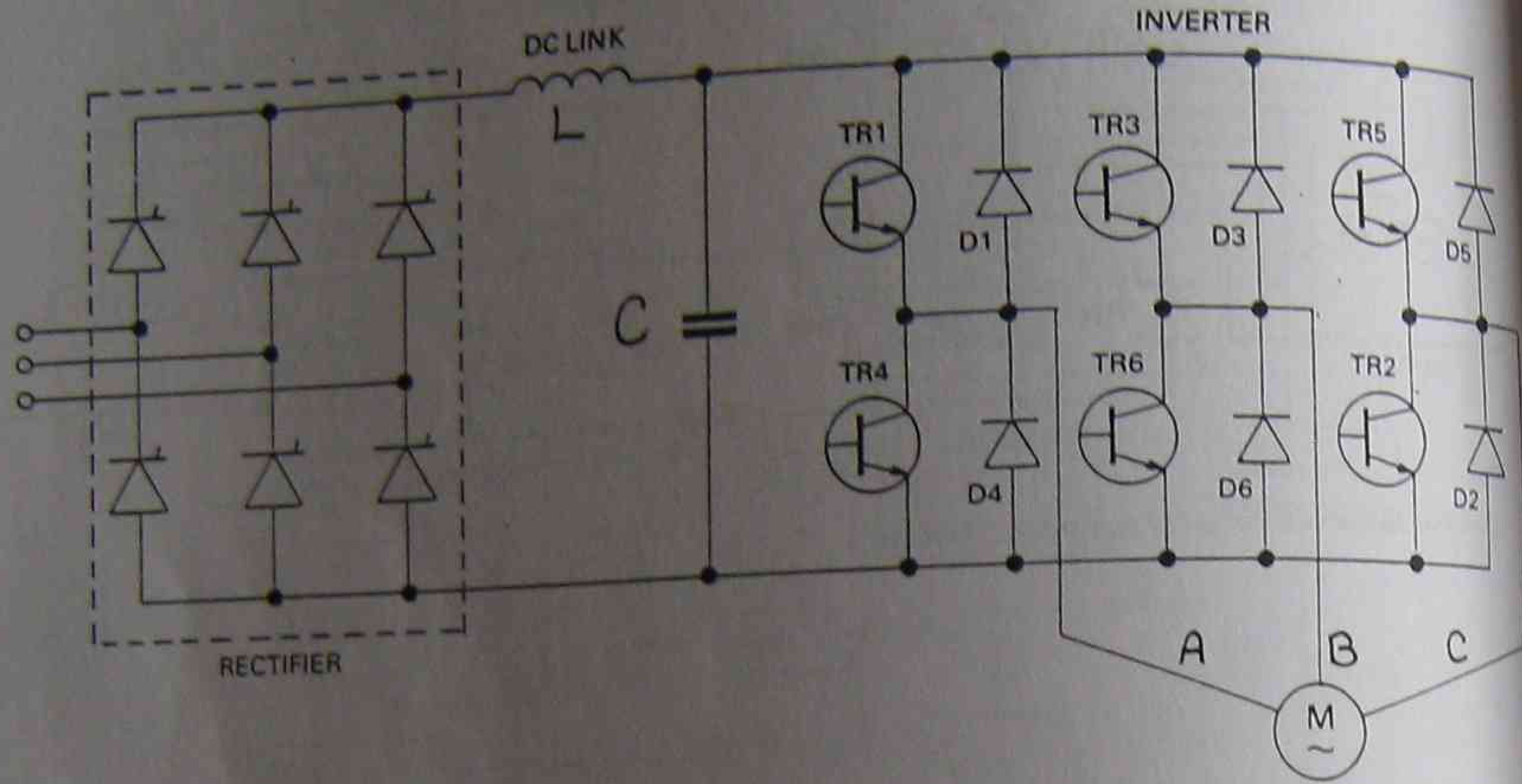
The input bridge, shown in more detail in Figure 11–21, is a conventional three-phase diode bridge rectifier. It consists of diodes *D13—D18*. The purpose of the rectifier is to change the incoming three-phase power to a constant DC voltage bus. Capacitor C_1 represents an electrolytic capacitor bank. This capacitor is charged to bus potential. With a 460 VAC line voltage, C_1 will be charged to about 620 V.

The second section of the power circuit is the chopper. The chopper is an electronic switch that alternatively connects and disconnects the coils of a large inductor from the DC bus. A simplified diagram of the chopper is shown in Figure 11–22.

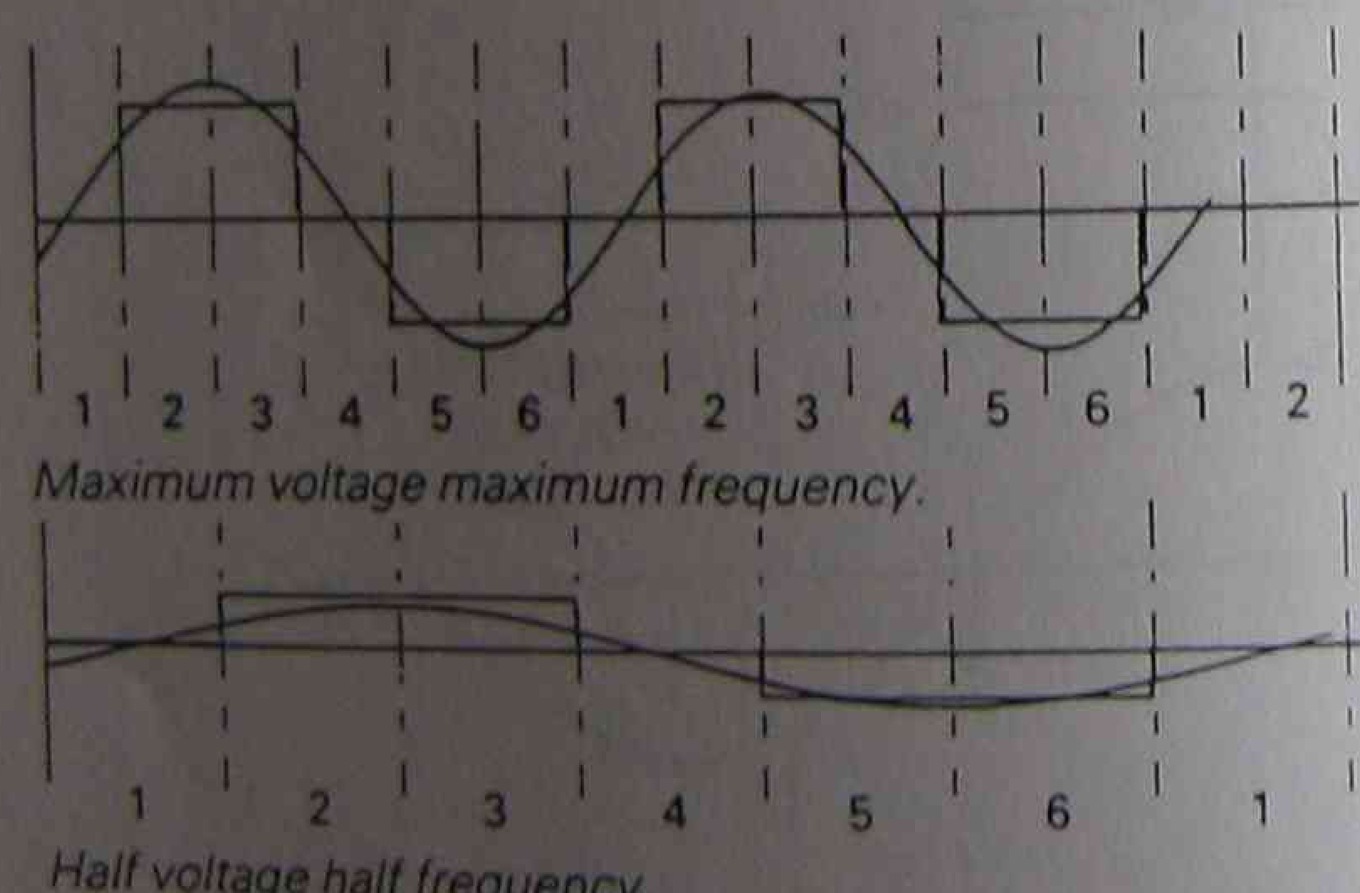
When the coils are connected to the constant potential DC bus, the current will increase. This position of the electronic switch is called increase or INC. When the switches are in the open position, the inductors *L18* and *L19* maintain the current flow without help from the DC bus. This takes energy out of the inductor and causes the current to decrease. This position of the switch is called decrease or DEC.

The load current is sensed by a Hall-effect device, which gives an output voltage proportional to the flux created by the load current. This proportional signal is then fed back to the regulator circuit where it is compared to a value that the system requires to make the load (motor) perform. The regulator circuits then vary the time spent in the decrease state versus the time spent in the increase state. This action controls the load current at the desired value.

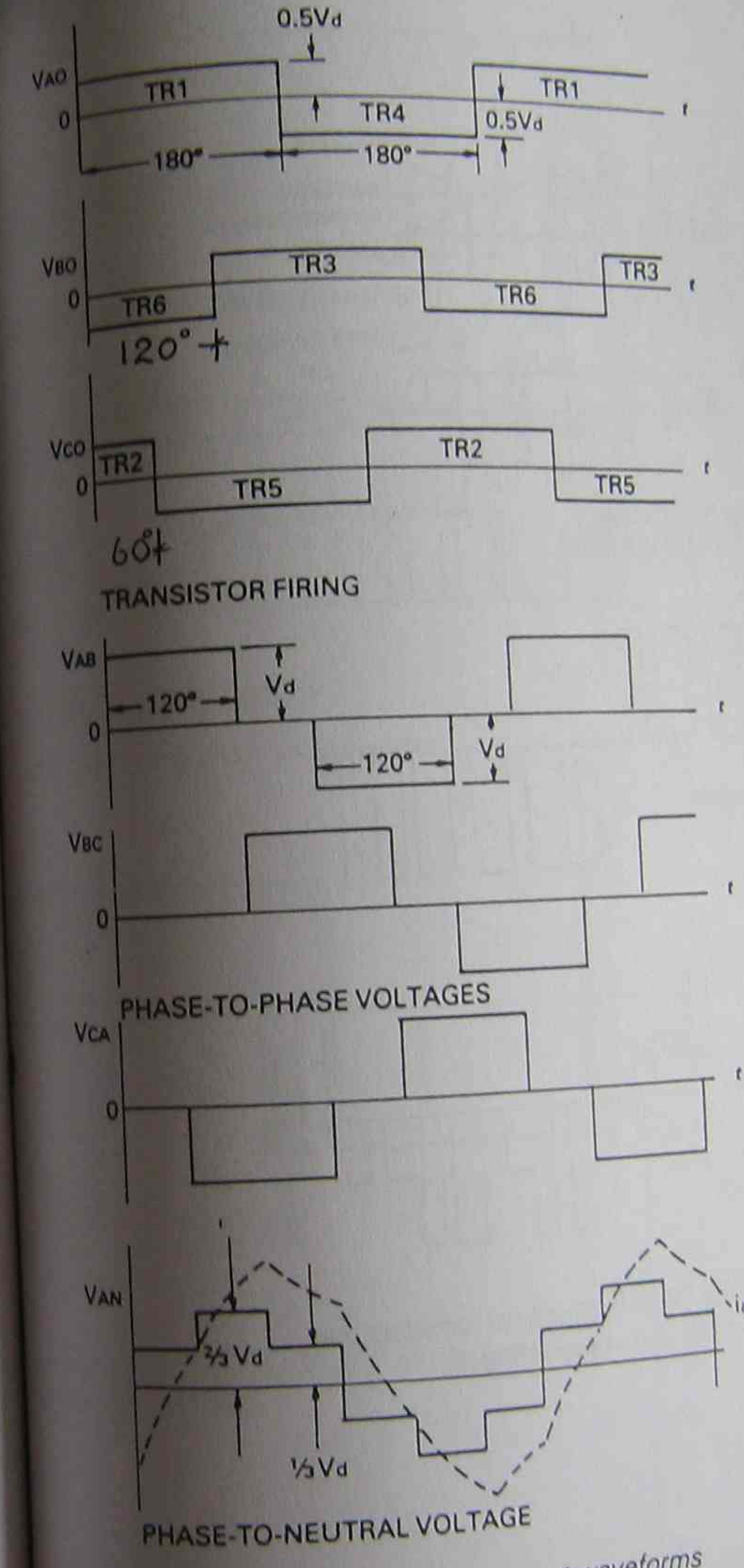
The current-regulated section responds to changes in load impedance. If the load changes its impedance or becomes a short circuit, the current will not exceed the value the system demands. Any tendency for the current to rise too high will be sent back to the comparator and will cause less time to be spent in the increase state. The physical presence of the inductance of *L18* and *L19* prevents the current from changing more rapidly than the rate the regulator can cope with. Although mechanical switches are shown in Figure 11–22, actual switches are semiconductor devices.



1 Basic dc link voltage-fed invertor square wave drive.



3 Constant volt/Hz control of square sine wave inverter.



2 Synthesis of inverter voltage output waveforms

Principles of vector control

Part two of an article discussing steady-state and dynamic operating characteristics of vector controlled induction motors compared with dc motors for variable speed applications.

By Dr Dal Y Ohm

Vector control principles are based on the synthesis of ac induction motor current. Consider equations (4) and (8):

$$T(t) = Kd\ lf\ la(t) \quad \text{(dc Motor)} \qquad (4)$$

$$T = Ka\ lm(t)\ lt(t)\ \sin\alpha \quad \text{(Induction)} \qquad (8)$$

where:

α = Phase difference between lm(t) and lq(t)

For two different types of motors, torque equations are very similar except the term sin α. In the dc motor, this angular relationship is still present but is fixed to 90° by the motor design. If the angular position of brushes is allowed to vary, corresponding sinusoidal terms can be applicable in a dc motor, too. The principle of vector control is to synthesise stator current so that these two component currents maintain orthogonality and are controlled independently in all dynamic situations. Decoupling these two current components maximises the efficiency of the produced torque, and provides operational characteristics similar to the dc motor.

The difference between the dc motor and the induction motor is that in the induction motor the airgap flux rotates whereas it is stationary in the dc motor. Because rotor current, or rotor mmf, produced from this current travels past the rotor at slip speed, and slip frequency EMF is generated in the rotor circuit by the transformer action, the relative angular position of rotor mmf is stationary relative to the stator mmf.

If we use a synchronously rotating reference frame as a reference coordinate system, both the stator and rotor fluxes are stationary and their mutual interaction generates continuous torque.

A mathematical linear transformation is possible between a three phase stationary reference frame and a two phase rotating reference frame with d and q axes. In the rotating reference frame, variables like voltages or currents are purely real quantities (like dc quantities) without modulation. In this synchronous frame, we can define ld and lq, which correspond to rms values of lm(t) and lt(t) if leakage inductances are neglected. Thus, equation (8) can be written as:

$$T = K\ ld\ lq\ \sin\alpha \qquad (10)$$

Here, an analogy to the dc motor is possible, where ld corresponds to field current, and lq corresponds to armature current. Because the two current components are orthogonal to each other (ld lags lq by 90°), stator current is the vector sum, ie:

$$l_s = \sqrt{ld^2 + lq^2} \qquad (11)$$

These vector relationships are shown in Figure 5. In the induction motor, ls and slip are mutually dependent quantities. Once lq is set by the torque requirement, angular slip frequency ω_s must satisfy:

$$\omega_s = \frac{lq}{Tr\ ld} \qquad (12)$$

where

Tr = Rotor time constant (Lr/Rr) determined by the motor design. As in a separately excited dc motor, the magnitude of magnetising current, ld, is fixed to a constant value below base speed and reduced inversely proportional to speed above base speed. Torque producing current lq is controlled to meet the torque requirement of the load.

To supply synthesised stator current to the motor, ld and lq must be transformed back to three phase sinusoidal phase currents. This inverse transformation requires information on the instantaneous angular position of the flux. Two methods can be considered in obtaining this airgap flux position. "Direct vector control" actually measures by using flux sensors. The "indirect method" estimates it by integrating rotor speed and generated slip. The indirect method is more popular because measurement of flux requires additional hardware and complex signal processing. From now on, discussions will be limited to the indirect method. Here, the instantaneous phase of stator current is calculated by:

$$\varphi = \int (\omega_r + \omega_s)\ dt + \theta \qquad (13)$$

where:

$$\theta = \text{Atan}\ (lqs/lds) \qquad (14)$$

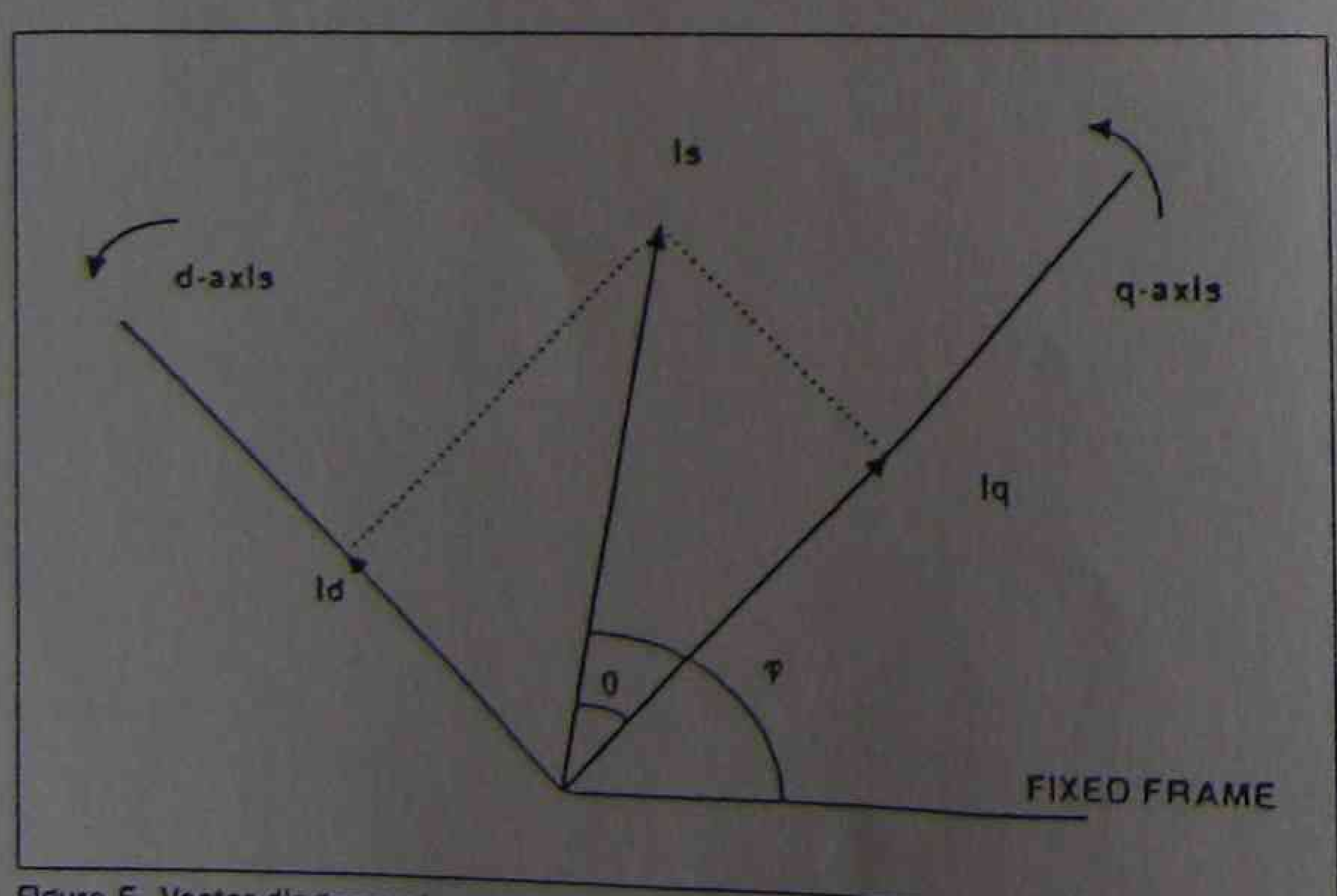


Figure 5. Vector diagram of sector current components

Note that stator current phase current is dependent upon slip, which is based on the knowledge of Tr in Equation (12). If the estimated Tr is not matched to the actual Tr, the two current components are not orthogonal. Therefore, the produced torque will be less than expected, resulting in poor efficiency and the inability to produce maximum torque. So, in vector control, correct tuning of parameter Tr is very important. With correctly tuned Tr, produced torque is:

$$T = Kv\ ld\ lq \qquad (15)$$

where:

Kv = (3/2)P(Lm/Lr). Clearly, the above equation is analogous to the dc machine equation (equation (4)). Torque characteristic curves are depicted in Figure 6. Note that the stator current is slightly reduced as speed increases above base speed. This is due to the vector relationship in equation (11). The major difference between an inverter-driven motor and a vector-controlled motor is that vector control characteristics are not limited to steady-state, but applicable in a dynamic situation like the dc motor.

With vector control, you can obtain dynamic operating characteristics comparable to a dc motor. The major advantage of the vector-driven induction motor is its rugged construction, reliability, low cost and simple construction for high-speed machines. In addition, constant-power operation is somewhat simpler than a separately excited dc motor because it is embedded in the vector control.

Vector control system implementation

We can present a practical vector control design with Baldor's ASBTS-20 series spindle drive. This system uses indirect vector control to get very accurate speed and positional controllability throughout its wide speed range. Often, this is required in high-performance machine tool spindle applications. Figure 7 shows a functional block diagram of the vector control used in the drive. Except the motor and mounted encoder, all electronics are packaged inside the drive. The drive includes many other functions — handshake logic with NC machine, protective functions and the operator interface etc — but discussions will be limited to vector control.

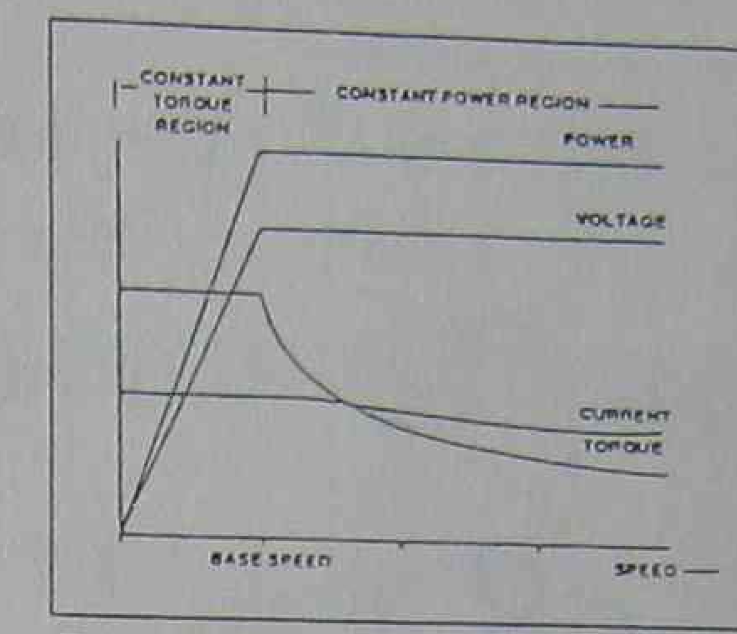


Figure 6. Vector controlled motor characteristics

For vector control, which involves many arithmetic calculations of extended resolution, at least a 16-bit microprocessor, or signal processor is required. The ASBTS-20 uses a NEC 78312 16-bit microcontroller with many functions handled by hardware, either through built-in microcontroller logic or on-board logic.

This effectively relieves software burdens required with fast sampling time.

From the speed command Vc from a host (either CNC or operator), velocity profile, Vr, is generated for every control interrupt cycle. The rate of change in the profile velocity depends on acceleration rate and speed. Vr is then compared to the actual speed of the motor, and the closed-loop compensator determines torque command, Tc, based on the present and past speed errors. Vector control starts from this point. Flux current component ld is calculated from the flux calculator process that simply modifies command flux ldc inversely proportional to the speed above base speed. Because the Tc command is directly proportional to lq (torque-producing current component), we are ready for vector calculation. From two variables ld and lq, magnitude and phase of stator current vector can be calculated from equations (11) and (14), and produced slip from equation (12). Rotor flux angle can be estimated by equation (13), so the appropriate arithmetic and digital integration process results in a rotor flux angle of the current interrupt cycle. Based on the magnitude and flux angle, the frame transformation process can be done via a combination of hardware and software. The resulting three phase stator current commands are transformed to an analogue format, filtered and amplified to feed motor current. To eliminate current phase lag due to inductance, a PWM amplifier with high gain current feedback is used.

There are two open-loop parameters that must be tuned properly. These are ldc and Tr (rotor time constant). To optimise performance, these must be tuned correctly with a load test. Because motor parameter Tr varies as motor temperature changes, peak torque capability may be deteriorated as temperature varies. Fortunately, for sizes of most spindle motors, its effect is not so critical in performance as in much larger size motors.

Dr Ohm is with the Baldor motion products group.

For further information contact Australian Baldor, 6 Stanton Rd, Seven Hills NSW 2147.

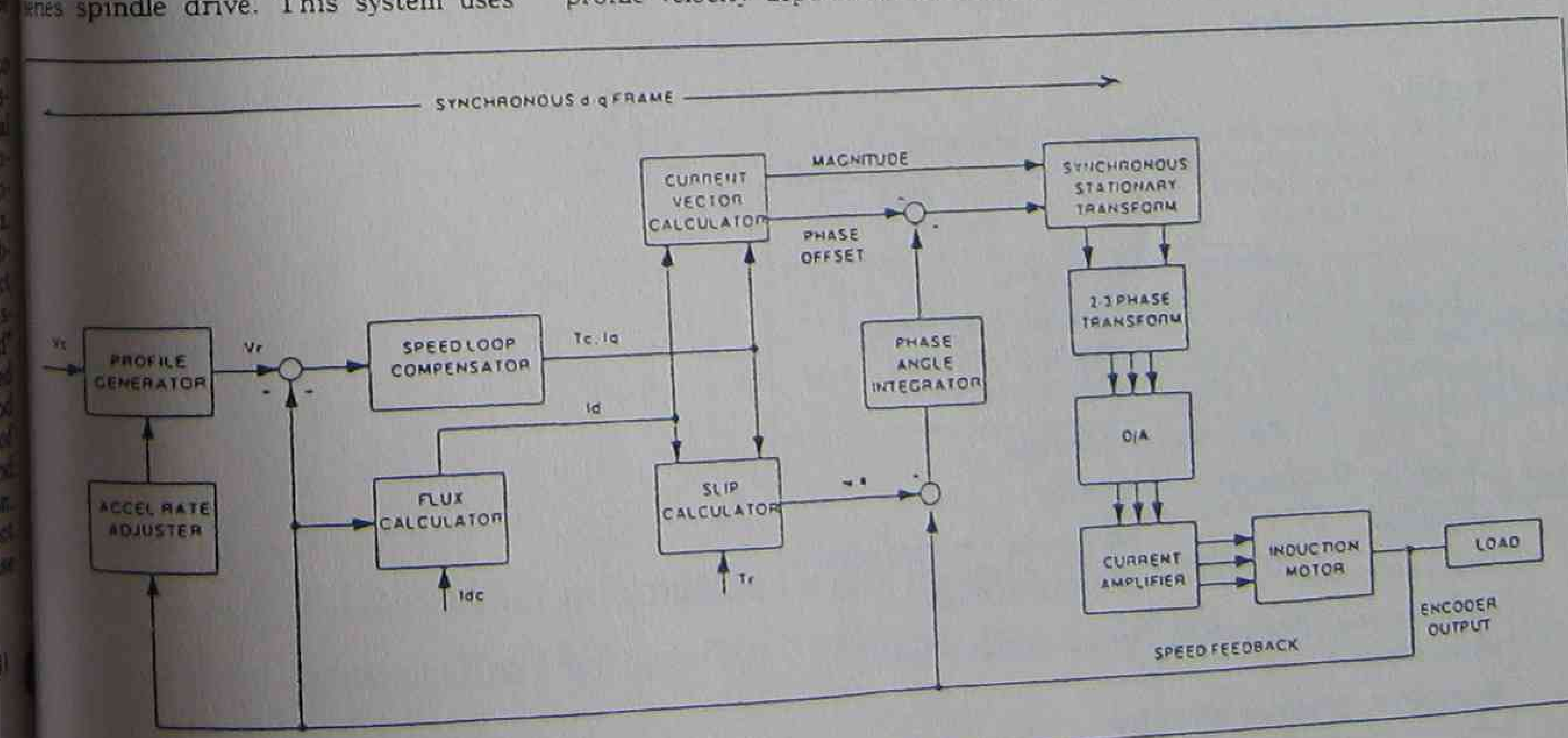
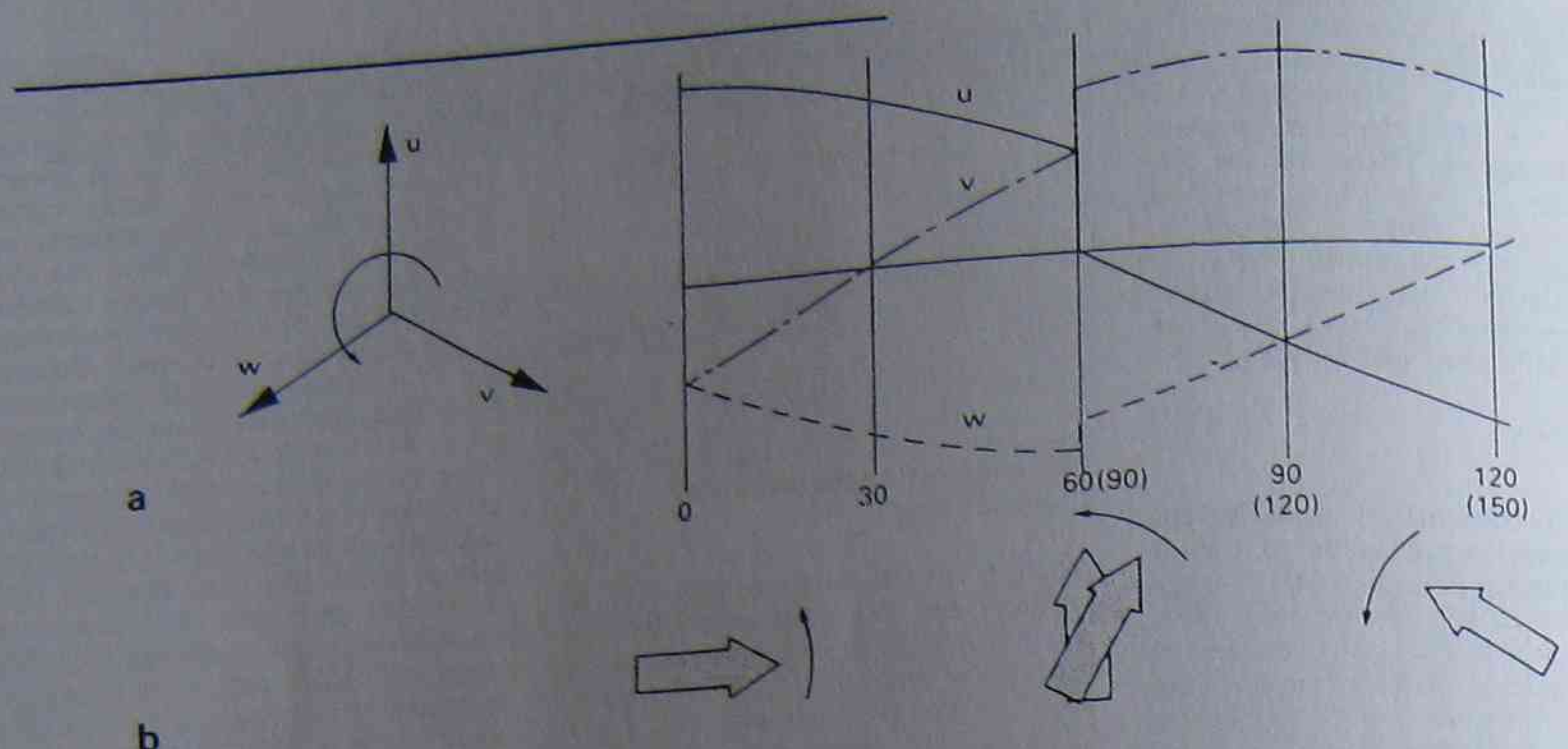
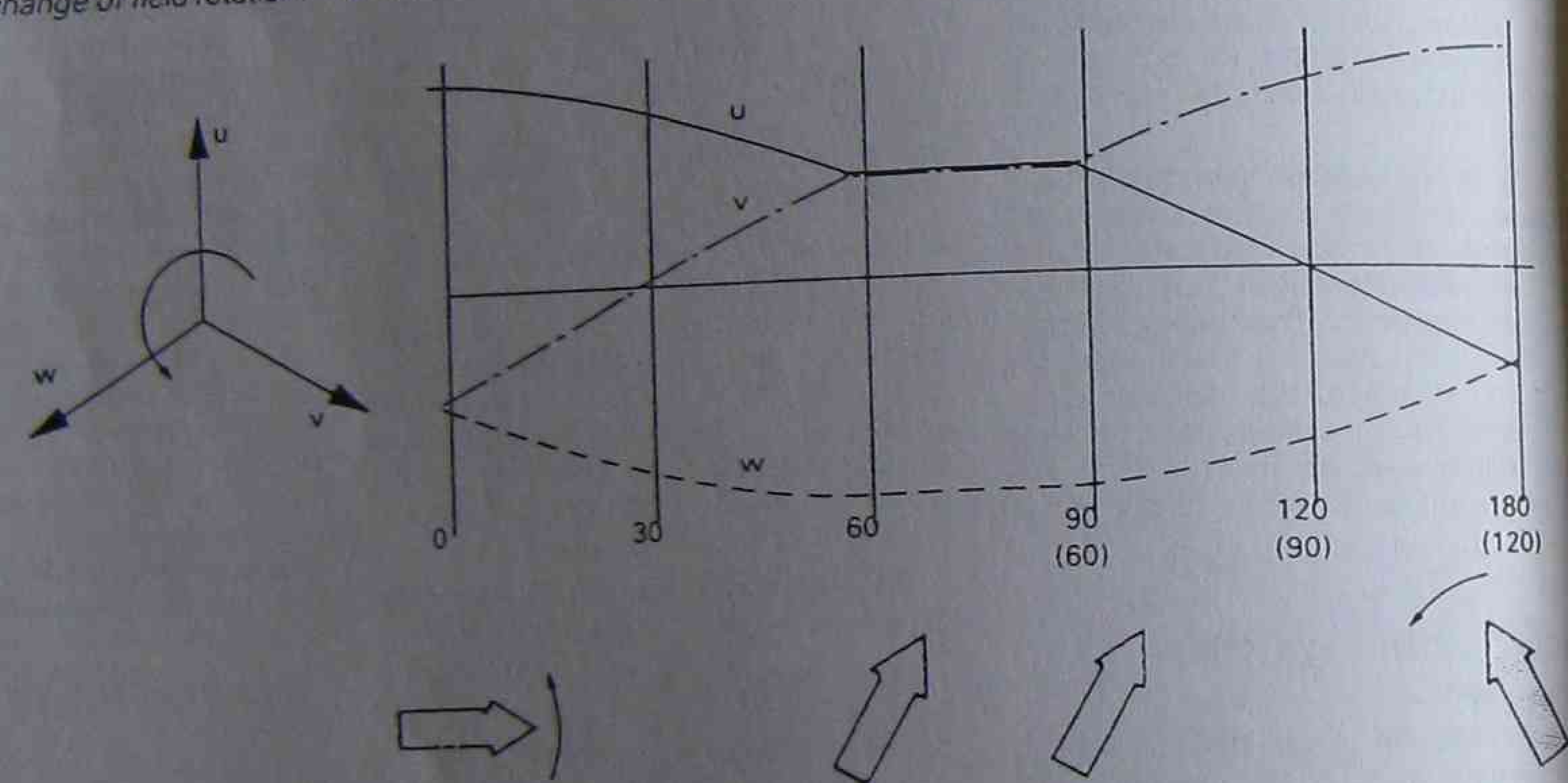


Figure 7. Vector controlled motor drive



2 *Step-change of field rotation:* **a** *Phase waveform;* **b** *Reorientation of flux vectors*



3 *Stationary field flux vector*

TABLE 1
3-Phase Rotating Field — Principal Variations

3-phase Current Vectors	Stator Flux Vector
Normal Mains Supply	
Balanced, sinusoidal, constant frequency and amplitude	Constant magnitude, rotating at constant angular velocity
PWM Supply Changes	
Character of Change:	Effect:
Amplitude	Magnitude of current vectors
Phase sequence	Direction of rotation
Balanced step-change of phase currents	Instantaneous advance
Balanced dc phase currents	Stationary

Sydney Institute of Technology

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Learners Practical Work Book

Module **NE76**

A.C. Motor Control

Area ....

Topic ....

Session No. ZENER DRIVE

For further information on this module, or this subject contact Jim Hafford, (02) 217 3620, Bld. K. Ultimo, S.I.T.


M.C.C. No.3
MOTOR CONTROL SYSTEMS
SYSTEM
POWER
ENABLE
SEQUENCE
TAFE
ELECTROTECHNOLOGY (I.E.)
SYSMAC S6
A.C. DRIVE
SQUIRREL CAGE INDUCTION MOTOR
STATOR VOLTAGE
STATOR CURRENT
FREQUENCY
D.C. DRIVE
PERMANENT MAGNET D.C. MOTOR
WOUND FIELD D.C. MOTOR
ARMATURE VOLTAGE
ARMATURE CURRENT
MOTOR SPEED (RPM)
D.C. SPEED No. 1
D.C. SPEED No. 3
D.C. SPEED No. 2
A.C. SPEED No. 1
EMERGENCY STOP


M.C.C. No.3
SYSMAC S6 PROGRAMMABLE CONTROLLER
omron
MOTOR CONTROL SYSTEMS
SYSTEM
POWER
ENABLE
SEQUENCE
TAFE
ELECTROTECHNOLOGY (I.E.)
REVERSE
POWER ON
FORWARD
STOP
A.C. DRIVE
SQUIRREL CAGE INDUCTION MOTOR
STATOR VOLTAGE
STATOR CURRENT
FREQUENCY
FWD REV
ON
START
STOP
D.C. DRIVE
PERMANENT MAGNET D.C. MOTOR
WOUND FIELD D.C. MOTOR
ARMATURE VOLTAGE
ARMATURE CURRENT
ARMATURE VOLTAGE
ARMATURE CURRENT
MOTOR SPEED (RPM)
TACHO GEN
D.C. SPEED No. 1
D.C. SPEED No. 2
D.C. SPEED No. 3
A.C. SPEED No. 1
SINE & SQUARE WAVE GENERATOR
SINE & SQUARE WAVE GENERATOR


WOUND FIELD D.C. MOTOR
START
STOP
ARMATURE VOLTAGE
ARMATURE CURRENT
ARMATURE VOLTAGE
ARMATURE CURRENT
MOTOR SPEED (RPM)
TACHO GEN
D.C. SPEED No. 1
D.C. SPEED No. 2
D.C. SPEED No. 3
A.C. SPEED No. 1
ZENER AUSTRALIA
ADJUSTMENTS
TORQUE LIMIT
ARM
TACHO
RUN
DC 1100
MOTOR SPEED CONTROL
P1 P2 COM P4 RO G2 SPD LD TL RUN A− A+ F− F+ N L
EMERGENCY STOP


MOTOR SPEED (RPM)
TACHO GEN
D.C. SPEED No. 1
D.C. SPEED No. 2
D.C. SPEED No. 3
A.C. SPEED No. 1
ZENER AUSTRALIA
ADJUSTMENTS
ACC DEC MAX TRQ IR CMP
MIN SPD RESP GAIN MAX SPD
TORQUE LIMIT
ARM
TACHO
RUN
DC 1100
MOTOR SPEED CONTROL
PWR
ARM
TLD
P1 P2 COM P4 RO G2 SPD LD TL RUN A– A+ F– F+ N L
KB
ZENER ELECTRIC
EMERGENCY STOP

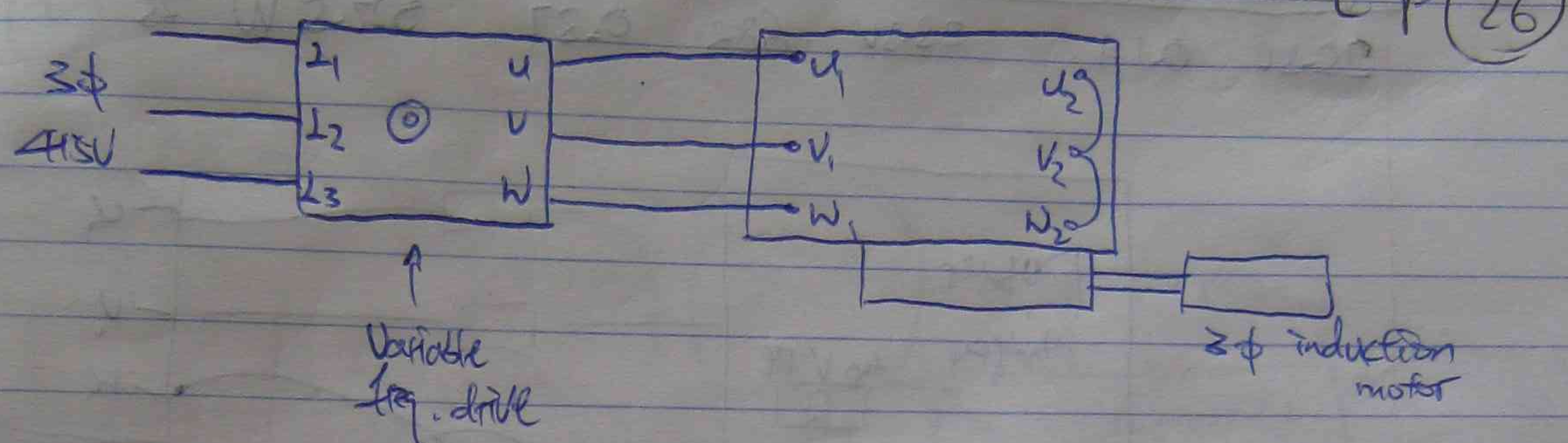

BALDOR
INDUSTRIAL MOTOR
BALDOR
INDUSTRIAL MOTOR


START
STOP
SSCONT
LR6a
LR6b
OFF
CLIPSAL
SR1
MR1a
MR1b
SR2
MR2a
MR2b
SR3
MR3
SR4a
SR4b
MR4a
MR4b
MR3


SR1
MR1a
MR1b
MR2a
MR2b
SR3
MR3
SR4a
SR4b
MR4a
MR4b
MR3

LAB ~~4~~4 3ϕ Induction motor variable speed drive.

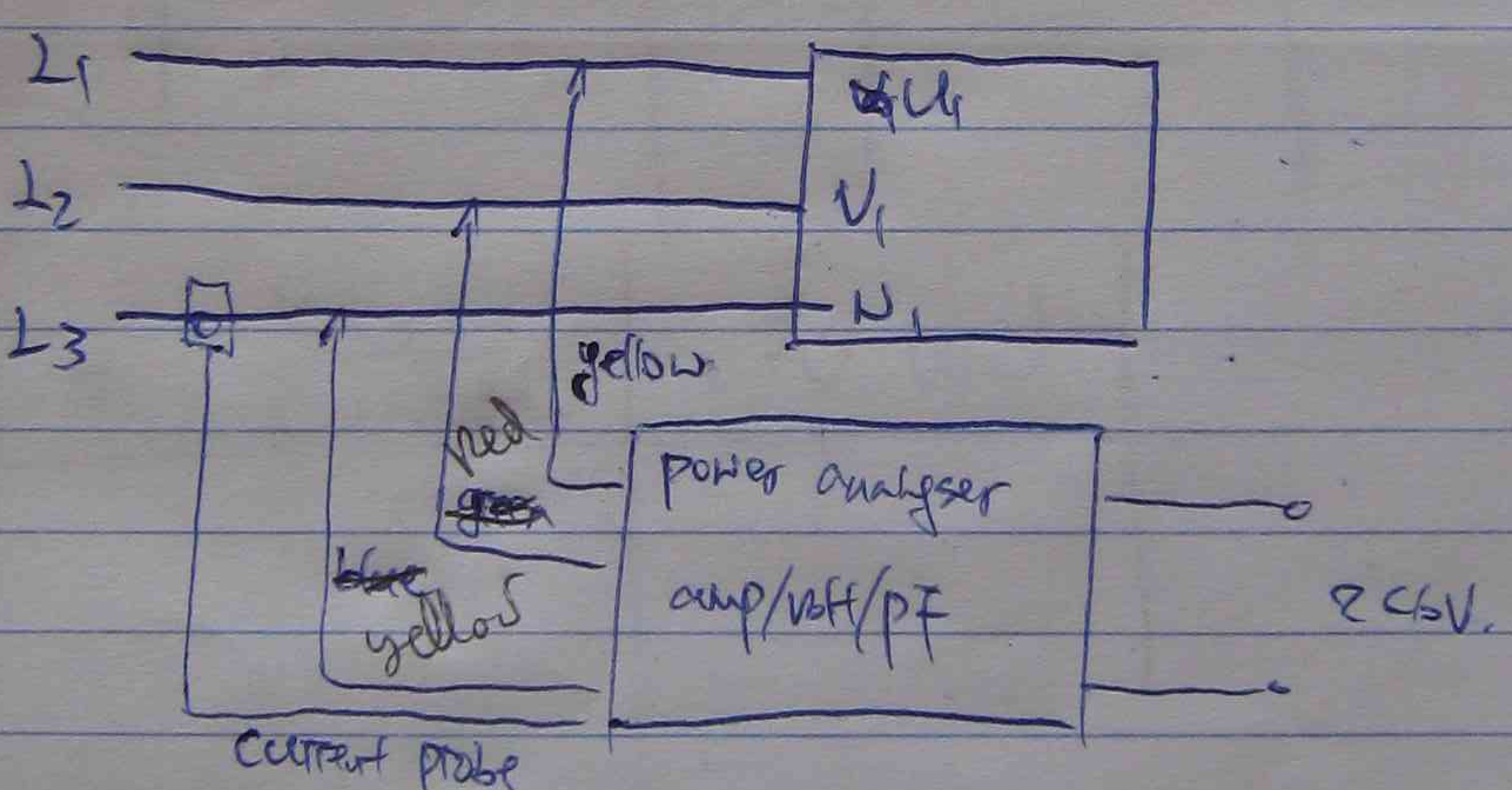
EP (26)



Frequency increase, speed of the motor increase.

EP (13)

Lab5. 3ϕ Induction motor power/torque measurement & no load test



Phase Resistance

$W_1 - W_2 = 4.3\Omega$

$U_1 - U_2 = 4.3\Omega$

$V_1 - V_2 = 4.3\Omega$

Amp = 0.1 A

Voltage = 25.5V

PF = 68.3

LAB(7)

P47 ~~3φ I~~ AC / DC variable speed Drive circuit Tracing

(1) Study the given ckt diag

(2) Trace the ckt ~~of~~ of the drive set by using given ckt

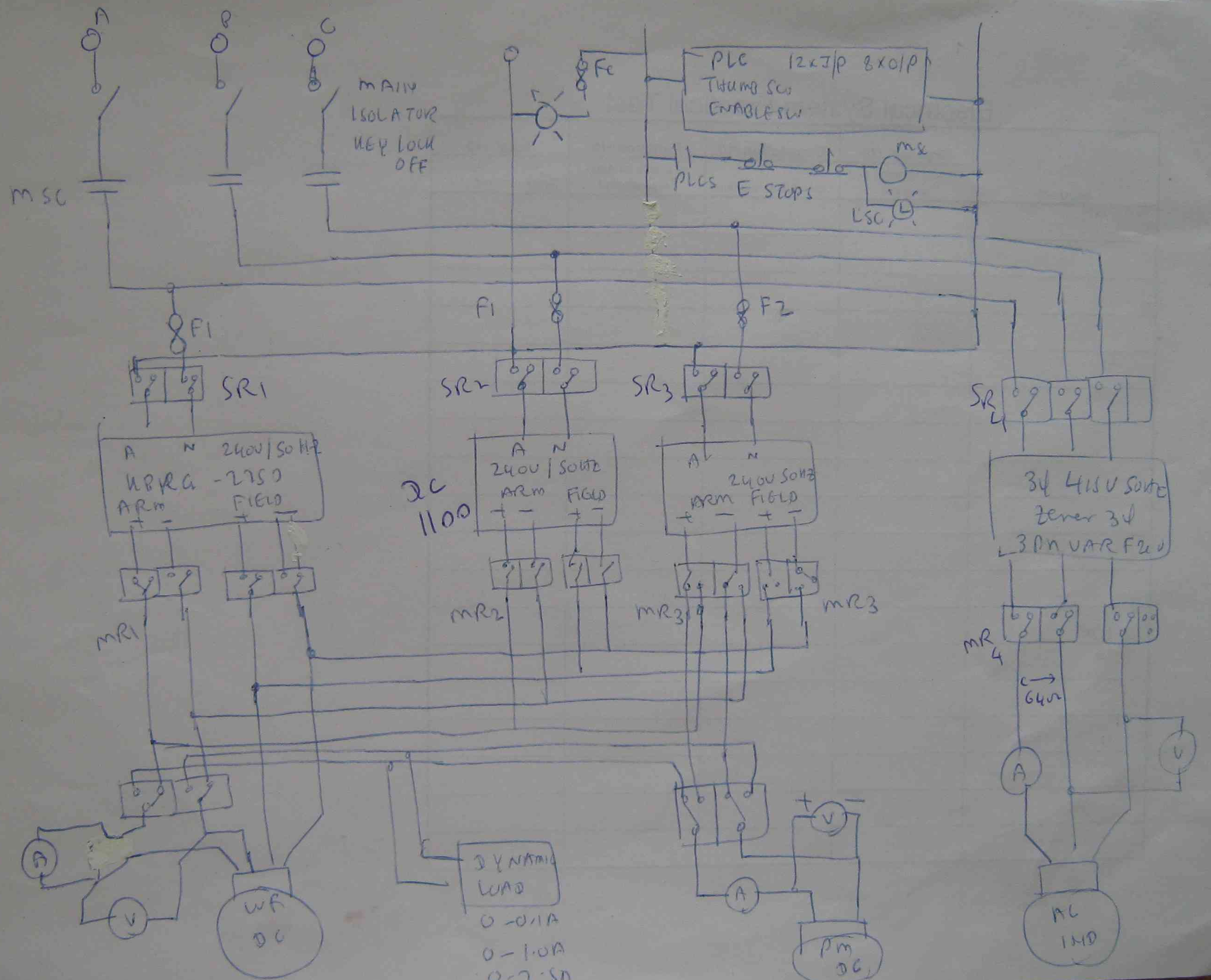
(3) Identify the following

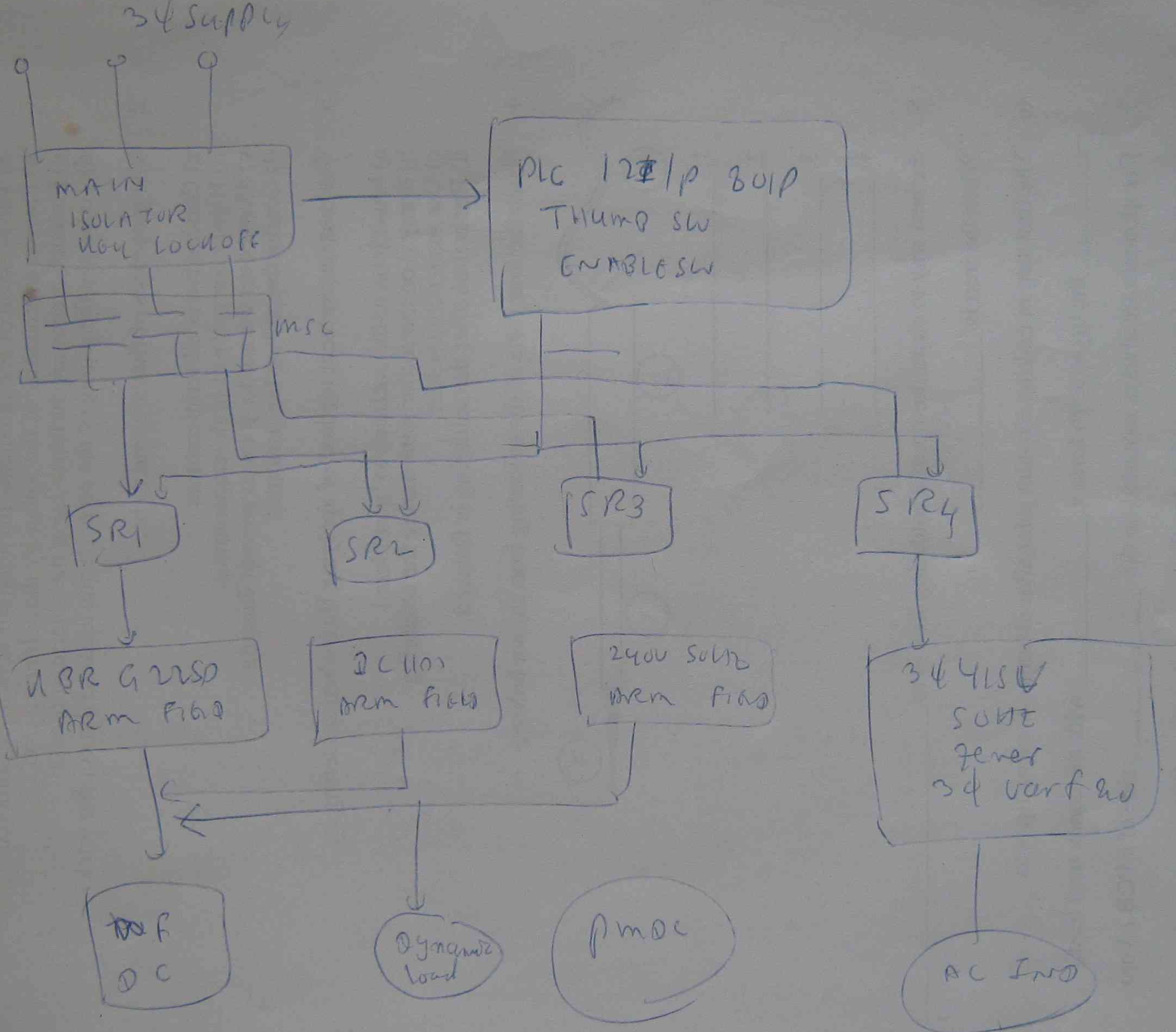
(1) 3φ power I/P
(2) main switch / CB for 3φ I/P / motor control system switches / system Enable / power
(3) ~~A~~ Volt meter / Ammeter connection
(4) Power I/P to control panel
(5) ~~A~~ connect/act control panel / connection between control panel.
(6) Power o/p from control panel to
    (a) 3φ motor
    (b) DC machine

~~(7)~~

Draw Schematic diagram with Label.

Present the ~~diagram~~ circuit diagram that you got


A
B
C
MAIN
ISOLATOR
KEY LOCK
OFF
MSC
Fc
PLC 12xI/P 8xO/P
THUMB SW
ENABLE SW
PLCS
E STOPS
MSC
LSC
F1
F1
F2
SR1
SR2
SR3
SR4
A N 240V/50Hz
KBRG -2750
ARM FIELD
DC 1100
A N
240V/50Hz
ARM FIELD
A N
240V 50Hz
ARM FIELD
3Φ 415V 50Hz
Zener 3Φ
L3Pn VAR F2V
MR1
MR2
MR3
MR3
MR4
64Ω
A
V
WF DC
DYNAMIC LOAD
0-0.1A
0-1.0A
0-2.5A
A
V
PM DC
A
V
AC IND



3φ Supply
MAIN ISOLATOR Ugh LOCKOFF
PLC 12 I/P 8 O/P
THUMB SW
ENABLE SW
MSC
SR1
SR2
SR3
SR4
UBR G22SD ARM FIGD
DC 110V ARM FIGD
240V SUPP ARM FIGD
3φ 415V SUPP Zener 3φ varf drv
DC
Dynamic load
PMDC
AC IND