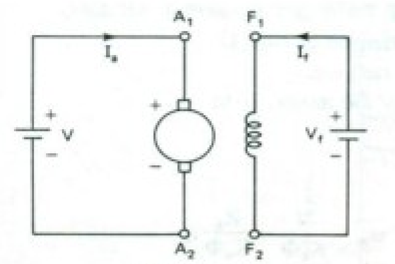
UNIT 2:THREE PHASE CONTROLLED CONVERTERS

Three types of electric **<u>of speed control techniques:</u>**

motors generally used for drive purposes. DC, Induction and Synchronous motor



Separately excited

The basic equations for DC motor are

$$E = K_e \phi w_m$$

$$V = E + I_a R_a$$

$$T = K_e \phi I_a$$

Where, E = back emf in volt;

φ= flux per pole in weber;

V = supply I = Armature

current in Amp;

R = Armature resistance in ohm;

w = speed of armature in rad/sec;

T = torque developed

$$w_m = \frac{V}{K_e \phi} - \frac{I_a R_a}{K_e \phi}$$

$$w_m = \frac{V}{K_e \phi} - \frac{R_a T}{(K_e \phi)^2}$$

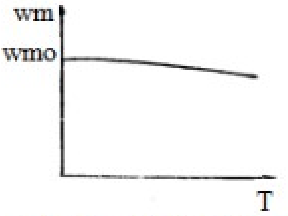
This equation can be applied to all series, shunt, compound and separately excited dc motor In the case of separately excited motors, if the field voltage is maintained constant,and assuming the flux as constant, then

$$K_e\phi = K \quad \text{(constant)}$$

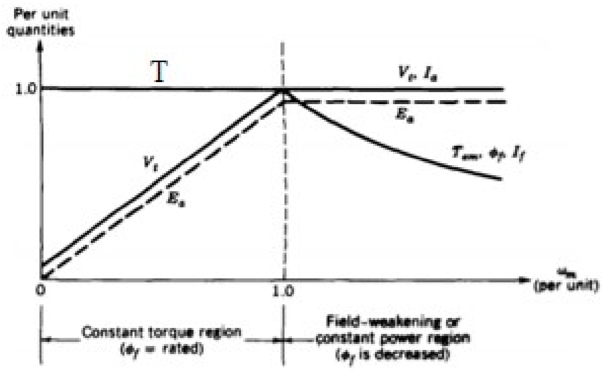
The speed equation is written for the separately as well as shunt motor is

$$w_m = \frac{V}{K} - \frac{R_a T}{K^2}$$

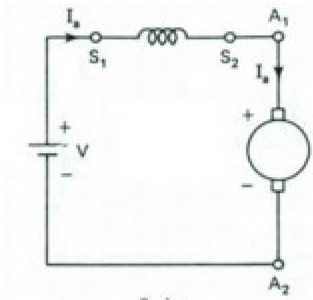
The speed increases from the zero upto the base speed. This method is called the constant torque method. Beyond the rated voltage, and rated armature current the voltage can not be increased further due to insulation problem. So, to control the speed the flux control can be done. By decreasing the flux, speed can be increased above the base speed w . This method is called constant power method where both voltage and armature current is kept constants. Further, in the below base speed region, the speed can be decreased from the no load speed w by increasing the load. When the load increased, the speed decreased from its no load speed. This motor is used where the speed regulation is good.



Speed-Torque ch. when load varies



Dc Series Motor:



Series

From the basic equation the speed can be written as

$$w_m = \frac{V}{K_e\phi} - \frac{R_a T}{(K_e\phi)^2}$$

In series motor, $T = K_e\phi I_a$, but $\phi \propto I_a$

So, $T = K_e K_f I_a^2$

$$w_m = \frac{V}{\sqrt{K_e K_f}}\frac{1}{\sqrt{T}} - \frac{R_a}{K_e K_f}$$

In the case of series motor, any increase in torque is accompanied by an increase in the armature current and therefore, an increase in flux. Because the flux increases with torque, the speed must drop to maintain a balance between the induced voltage and the supply voltage. The characteristic is therefore, highly drooping.

Methods of speed control :

From the speed-torque relation from the equation it is seen that, the speed can be controlled by any one of the following three methods.

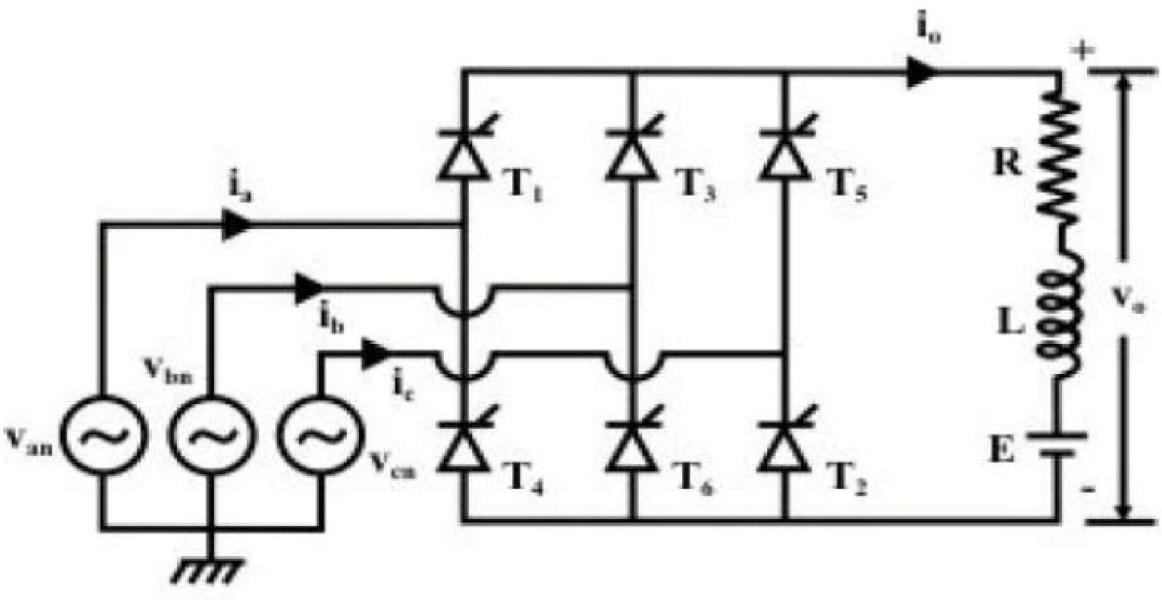
1.Armature voltage control

2. Armature resistance control (Rheostatic control)

3. Field flux control

THREE PHASE CONVERTER FED DC MOTOR:

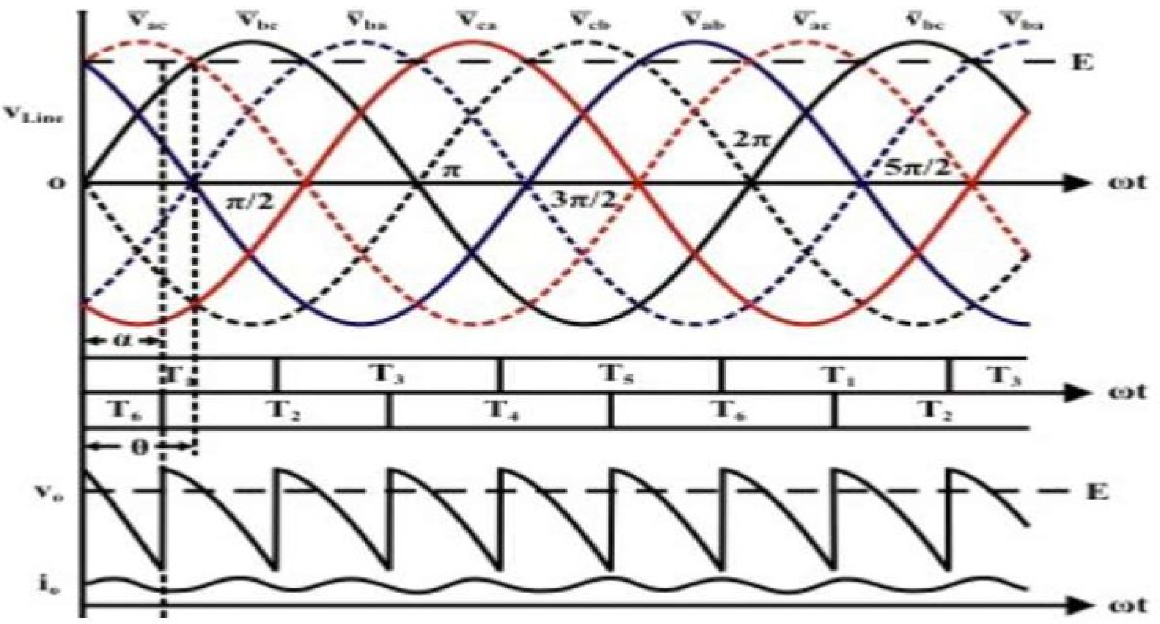
The three phase fully controlled bridge converter has been probably the most widely used power electronic converter in the medium to high power applications. The controlled rectifier can provide controllable output dc voltage in a single unit instead of a three phase autotransformer and a diode bridge rectifier. The controlled rectifier is obtained by replacing the diodes of the uncontrolled rectifier with thyristors. Control over the output dc voltage is obtained by controlling the conduction interval of each thyristor. In phase controlled rectifiers though the output voltage can be varied continuously the load harmonic voltage increase considerably as the average value goes down. Of course the magnitude of harmonic voltage is lower in three phase converter compared to the single phase circuit. Three phase converter is shown in fig.



For any current to flow in the load at least one device from the top group (T1, T3, T5) and one from the bottom group (T2, T4, T6) must conduct. Then from symmetry consideration it can be argued that each thyristor conducts for 120° of the input cycle. Now the thyristors are fired in the sequence T1 → T2 → T3 → T4 → T5 → T6 → T1 with 60° interval between each firing. Therefore thyristors on the same phase leg are fired at an interval of 180° and hence cannot conduct simultaneously. This leaves only six possible conduction mode for the converter in the continuous conduction mode of operation. These are T1T2, T2T3, T3T4, T4T5, T5T6, T6T1. Each conduction mode is of 60° duration and appears in the sequence mentioned. Table.1 shows the firing sequence of SCRs.

S.No	Firing angle	Conducting pair	Incoming SCR	Outgoing SCR	Line voltage (Load)
1	$30+\alpha$	T_6,T_1	T_1	T_5	V_{ab}
2	$90+\alpha$	T_1,T_2	T_2	T_6	V_{ac}
3	$150+\alpha$	T_2,T_3	T_3	T_1	V_{bc}
4	$210+\alpha$	T_3,T_4	T_4	T_2	V_{ba}
5	$270+\alpha$	T_4,T_5	T_5	T_3	V_{ca}
6	$330+\alpha$	T_5,T_6	T_6	T_4	V_{cb}

Fig. shows the waveforms of different variables. To arrive at the waveforms it is necessary to draw the firing sequence table which shows the interval of conduction for each thyristor. If the converter firing angle is “α” each thyristor is fired “α” angle after the positive going zero crossing of the line voltage with which it’s firing is associated. Once the conduction diagram is drawn all other voltage waveforms can be drawn from the line voltage waveforms. It is clear from the waveforms that output voltage and current waveforms are periodic over one sixth of the input cycle. Therefore this converter is also called the “six pulse” converter. The input current on the other hand contains only odds harmonics of the input frequency other than the triplex



v_ac
v_bc
v_ba
v_ca
v_cb
v_ab
v_ac
v_bc
v_ba
E
v_Line
2π
5π/2
o
π
π/2
3π/2
ωt
α
T_1
T_3
T_5
T_1
T_3
ωt
T_6
T_2
T_4
T_6
T_2
θ
v_o
E
i_o
ωt

If the line-to-neutral voltages are defined as

$$v_{an} = V_m \sin \omega t$$

$$v_{bn} = V_m \sin\left(\omega t - \frac{2\pi}{3}\right)$$

$$v_{cn} = V_m \sin\left(\omega t + \frac{2\pi}{3}\right)$$

the corresponding line-to-line voltages are

$$v_{ab} = v_{an} - v_{bn} = \sqrt{3}\, V_m \sin\left(\omega t + \frac{\pi}{6}\right)$$

$$v_{bc} = v_{bn} - v_{cn} = \sqrt{3}\, V_m \sin\left(\omega t - \frac{\pi}{2}\right)$$

$$v_{ca} = v_{cn} - v_{an} = \sqrt{3}\, V_m \sin\left(\omega t + \frac{\pi}{2}\right)$$

The average output voltage is found from

$$V_{dc} = \frac{3}{\pi} \int_{\pi/6+\alpha}^{\pi/2+\alpha} v_{ab}\, d(\omega t) = \frac{3}{\pi} \int_{\pi/6+\alpha}^{\pi/2+\alpha} \sqrt{3}\, V_m \sin\left(\omega t + \frac{\pi}{6}\right) d(\omega t)$$

$$= \frac{3\sqrt{3}\, V_m}{\pi} \cos \alpha$$

The maximum average output voltage for delay angle, $\alpha = 0$, is

$$V_{dm} = \frac{3\sqrt{3}\, V_m}{\pi}$$

and the normalized average output voltage is

$$V_n = \frac{V_{dc}}{V_{dm}} = \cos \alpha$$

The rms value of the output voltage is found from

$$V_{rms} = \left[\frac{3}{\pi}\int_{\pi/6+\alpha}^{\pi/2+\alpha} 3V_m^2 \sin^2\left(\omega t + \frac{\pi}{6}\right) d(\omega t)\right]^{1/2}$$

$$= \sqrt{3}\, V_m \left(\frac{1}{2} + \frac{3\sqrt{3}}{4\pi} \cos 2\alpha\right)^{1/2}$$

A three-phase full-controlled converter controlls a separately excited dc motor. At 900 rpm, it develops full load torque at an armature current of 20 A at 430 V, the triggering delay angle being zero. Find the rms voltage per phase of the ac supply and the range of delay angle control required to provide a speed between 900 rpm and 450 rpm at full load torque.

Solution Converter average output voltage

$$V_a = 430 \text{ V} \qquad \text{which is also the armature voltage}$$

$$430 = E_b + I_a R_a \qquad \left(\because \quad V_a = \frac{3\sqrt{3}\sqrt{2}}{\pi\sqrt{3}} \cdot V_L \cos\alpha \right)$$

When the firing angle is 0°,

$$V_a = 1.35\ V_L \qquad [\because \text{ the converter is a three-phase full wave rectifier}]$$

$$\therefore \qquad V_L = \frac{V_a}{1.35} = \frac{430}{1.35} = 318.5 \text{ V}$$

It may be noted that when the motor would run 450 rpm, the back emf would be half that of back emf at 900 rpm.

$\therefore$ At 450 rpm,

$$V_a = \frac{E_b \text{ (at 900 rpm)}}{2} + I_a R_a$$

$$V_a = \frac{430 - 20 \times 0.2}{2} + 20 \times 0.2 \qquad [\because \ I_a = 20 \text{ A and } R_a = 0.2\ \Omega]$$

$$V_a = 217 \text{ V}$$

This value indicates V_{dc} at 450 rpm.

However,

$$V_a(\alpha) = V_a \cos\alpha$$

$$217 = 430 \cos\alpha$$

$$\alpha = 59.69°$$

A 440 V three-phase full converter controls a 100 kW, 900 rpm dc shunt motor at its armature terminals. Find the triggering angle and the power factor at the rated speed. Assuming the input ac supply to be the 415 V, what is the value of the triggering angle at 50% of the rated speed?

Solution For a three-phase full wave converter,

$$V_a(\alpha) = \frac{3\sqrt{3}}{\pi} \cdot \frac{\sqrt{2}V_{ac}}{\sqrt{3}} \cos \alpha$$

$$V_{a(\alpha)} = 1.35\ V_{a(0)} \cos \alpha$$

However, at rated speed,

$$V_{a(\alpha)} = 440 \text{ V}$$

$$V_{a(0)} = 415 \text{ V}$$

$$440 = 1.35 \times 415 \cos \alpha$$

$$\cos \alpha = \frac{440}{1.35 \times 415} = 0.78$$

$$\alpha = 38.24°$$

On the other hand, for 50% rated speed,

$$V_{a(\alpha)} = 0.5 \times 440 = 220 \text{ V}$$

Thus,

$$220 = 1.35 \times 415 \times \cos \alpha$$

Two 3-ϕ full converters are connected anti-parallel to form a 3-ϕ dual converter of circulating current type. The input to dual converter is 3-ϕ, 400 V, 50 Hz, and the peak valve of circulating current is to be limited to 20 A. Find the value of inductance needed for a firing angle of 60°.

Solution We have

$$i_{Lr} = \frac{3\sqrt{2}E_a}{\omega L_r}(1 - \sin \alpha)$$

$$= \frac{3 \times \sqrt{2} \times (400/\sqrt{3})}{2\pi \times 50 L_r} (1 - \sin 60°)$$

$$L_r = 20.78 \text{ mH}$$

Example A 220 V, 750 rpm, 200 A, separately excited dc motor has an armature resistance of 0.05 Ω. Armature is fed from a 3-ϕ non-circulating current mode dual converter, consisting of fully controlled rectifiers *A* and *B*. Rectifier *A* provides motoring operation, in the below forward direction, and rectifier *B* is in reverse direction. Supply voltage of ac source is 400 V. Calculate the firing angle of the rectifier for the motoring operation at rated torque and 600 rpm, assuming continuous conduction.

Solution We have

$$E_{b1} = 220 - 200 \times 0.05 = 210 \text{ V}$$

$$E_{b2} = \frac{600}{250} \times 210 = 168 \text{ V}$$

$$\therefore \quad E_{a2} = E_{b2} + I_a R_a$$

$$= 168 + 200 \times 0.05$$

$$= 178 \text{ V}$$

$$\therefore \quad 178 = \left(\frac{3\sqrt{3}E_m}{\pi}\right)\cos\alpha$$

$$178 = \left(\frac{3\sqrt{3}}{\pi}\right) \times \frac{\sqrt{2}}{\sqrt{3}} V_{ac} \cos\alpha$$

$$178 = \frac{3\sqrt{2}}{\pi} V_m \cos\alpha$$

$$\cos\alpha = \frac{178}{1.35 \times 400} = 0.329$$

$$\therefore \quad \alpha = 70.77°$$

4.2.1.1

<u>Three-Phase Fully-Controlled Dual-Converter Drives System:</u>

Fig. shows a three-phase fully controlled dual-converter power circuit, the voltage and current waveforms, and firing sequence of thyristors. The three-phase six-pulse bridge can be operated in a converter or inverter mode depending upon the delay angle to be less than or above 90 Each SCR remains on for 120 duration and is turned off only when the next SCR of the same portion in sequence is gated. Once SCR each in upper and lower portions of the bridge conducts at a time for 120 duration and is turned off only when the next SCR of the same portion in sequence is turned on. SCRs are switched on in a sequence at every 60 angle thus the gate pulses should have a frequency six times higher than the source frequency. Moreover, to keep each SCR on for 120 duration either each SCR should be gated twice at the interval of 60 by short gate pulses or each gate pulse should be for more than 60.

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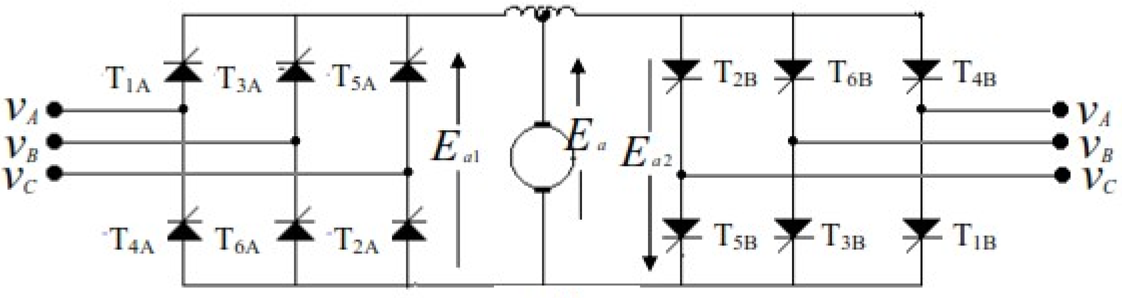
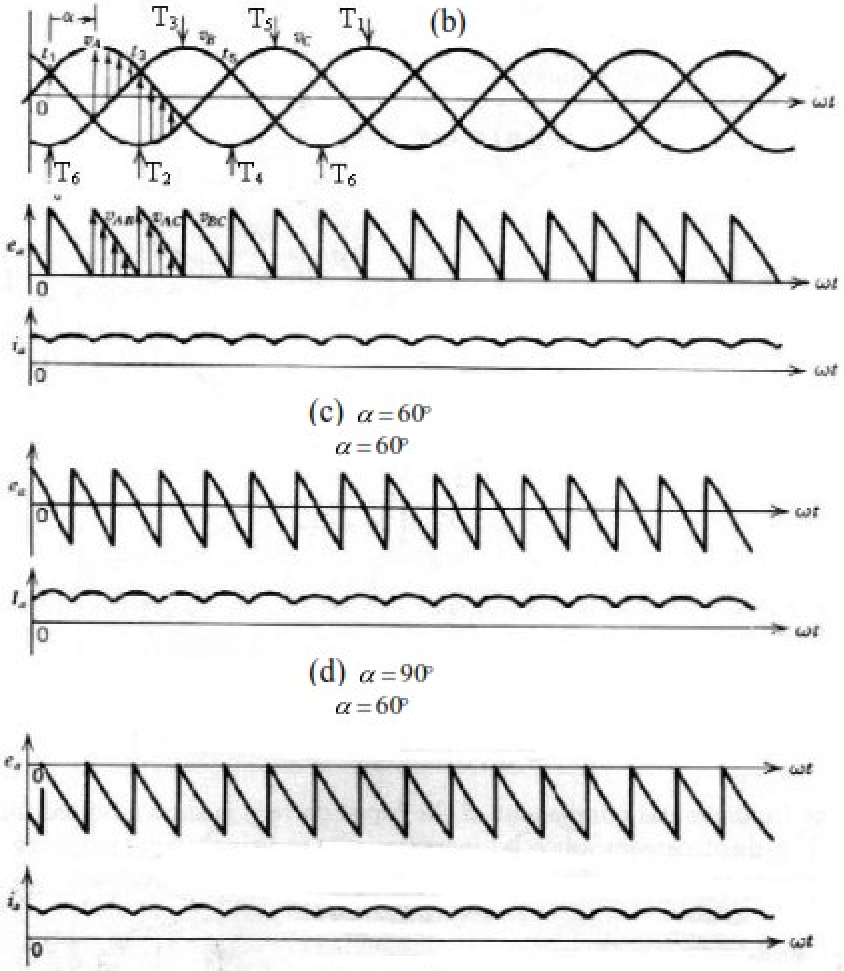


(a)



(c) $\alpha = 60°$

(d) $\alpha = 90°$

(e) $\alpha = 120°$

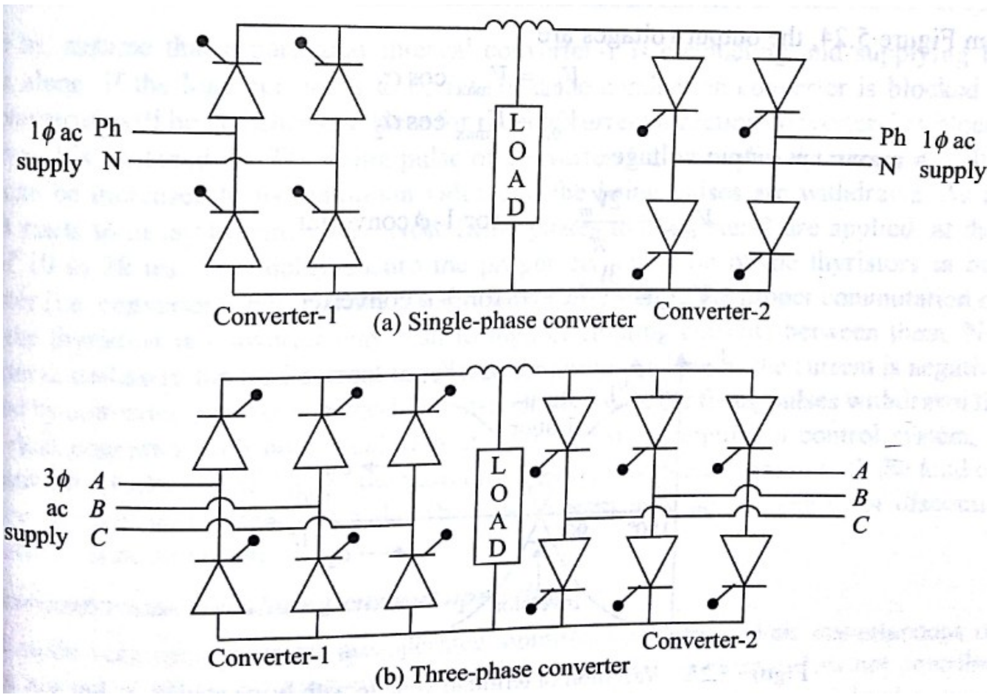
DUAL

DUAL CONVERTER

Half-converter and fully-controlled converter are discussed in the previous section. All half-controlled converters provide single-quadrant operation only. They convert ac power to dc power which is controllable. The operation of all such converters is confined to the first quadrant in the I_{dc}-V_{de} plane, where V_{de} and I_d, represent average output voltage and average output current respectively. The average output voltage of all fully-controlled converters can be either positive or negative, they can operate in two quadrants, first and fourth in the I_{dc}-V_{de} plane. The first quadrant operation indicates the rectification mode with the power flow from ac to dc while the fourth quadrant operation indicates the inversion mode with the power flow from the dc circuit to the ac supply network.

In order to obtain the four-quadrant operation without the aid of any mechanical switch two converters are connected in anti-parallel across the load circuit. Such arrangement is known as a dual converter. Both voltage and current of either polarity are obtained with a dual converter. Figure show single-phase and three-phase dual converter

using bridge type converter circuits. The output terminals of each converter having the same potential are connected together through a reactor. If we assume ideal converters with a negligible ripple in the output voltage, the output voltage of each converter must be equal to the load voltage.

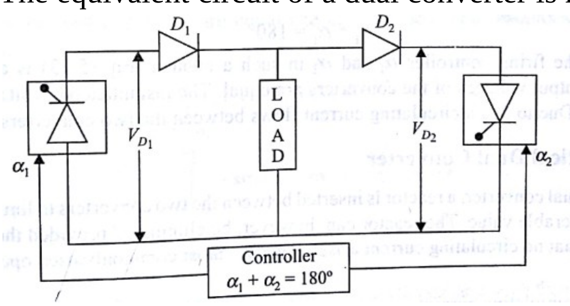


(a) Single-phase converter

(b) Three-phase converter

Ideal Dual Converter

The equivalent circuit of a dual converter is represented in Figure



dual converter consists of two ideal converters labeled as converter-1 and converter-2 as Shown in Figure . Since converters are assumed to be ideal, their output voltage is ripple-free. V_{01} and V_{02} represent average output voltage magnitudes of converter-1 and converter-2, respectively. direction.

Two diodes D1 and D2 are connected in series with the output voltages of converter-1 and converter-2 respectively The connection of diodes indicates that each converter can conduct current In Only one direction. But the load current can flow in either

From Figure 5.24, the output voltages are

$$V_{01} = V_{max} \cos \alpha_1$$
$$V_{02} = V_{max} \cos \alpha_2$$

where, V_{max}= maximum output voltage

$$V_{max} = \frac{2V_m}{\pi}, \quad \text{for 1-}\phi \text{ converter}$$

$$V_{max} = \frac{3V_m}{\pi}, \quad \text{for 3-}\phi \text{ converter}$$

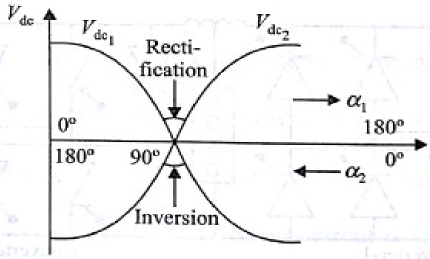


Figure 5.25 Variation of terminal voltage with firing angle.

Equating the output voltage of converter-1 and converter-2, we have

$$V_{01} = V_0 = -V_{02}$$

Substituting V_{01} and V_{02} from Eqs. (5.20) and (5.21) in Eq. (5.22), we obtain

$$\cos \alpha_1 + \cos \alpha_2 = 0$$
$$\alpha_1 + \alpha_1 = 180°$$

By changing the firing controller α_1 and α_2 in such a manner, is always satisfied. The average output voltages of the converters are equal instantaneous voltages V_{01} and V_{02} are not equal. Due to this a circulating current flows between the converters.