Module 2

AC to DC Converters

Lesson 11

Single Phase Half Controlled Bridge Converter

Operation and analysis of single phase half controlled converters

Instructional Objectives

On completion the student will be able to

- Draw different topologies of single phase half controlled converter.
- Identify the design implications of each topology.
- Construct the conduction table and thereby draw the waveforms of different system variables in the continuous conduction mode of operation of the converter.
- Analyze the operation of the converter in the continuous conduction mode to find out the average and RMS values of different system variables.
- Find out an analytical condition for continuous conduction relating the load parameters with the firing angle.
- Analyze the operation of the converter in the discontinuous conduction mode of operation.

11.1 Introduction

Single phase fully controlled bridge converters are widely used in many industrial applications. They can supply unidirectional current with both positive and negative voltage polarity. Thus they can operate either as a controlled rectifier or an inverter. However, many of the industrial application do not utilize the inverter mode operation capability of the fully controlled converter. In such situations a fully controlled converter with four thyristors and their associated control and gate drive circuit is definitely a more complex and expensive proposition. Single phase fully controlled converters have other disadvantages as well such as relatively poor output voltage (and current for lightly inductive load) form factor and input power factor.

The inverter mode of operation of a single phase fully controlled converter is made possible by the forward voltage blocking capability of the thyristors which allows the output voltage to go negative. The disadvantages of the single phase fully controlled converter are also related to the same capability. In order to improve the output voltage and current form factor the negative excursion of the output voltage may be prevented by connecting a diode across the output as shown in Fig 11.1(a). Here as the output voltage tries to go negative the diode across the load becomes forward bias and clamp the load voltage to zero. Of course this circuit will not be able to operate in the inverter mode. The complexity of the circuit is not reduced, however. For that, two of the thyristors of a single phase fully controlled converter has to be replaced by two diodes as shown in Fig 11.1 (b) and (c). The resulting converters are called single phase half controlled converters. As in the case of fully controlled converters, the devices T_1 and D_2 conducts in the positive input voltage half cycle after T_1 is turned on. As the input voltage passes through negative going zero crossing D_4 comes into conduction commutating D_2 in Fig 11.1 (b) or T_1 in Fig 11.1 (c). The load voltage is thus clamped to zero until T_3 is fired in the negative half cycle. As far as the input and output behavior of the circuit is concerned the circuits in Fig 11.1 (b) and (c) are identical although the device designs differs. In Fig 11.1 (c) the diodes carry current for a considerably longer duration than the thyristors. However, in Fig 11.1 (b) both the thyristors and the diodes carry current for half the input cycle. In this lesson the operating principle and characteristics of a single phase half controlled converter will be presented with reference to the circuit in Fig 11.1 (b).

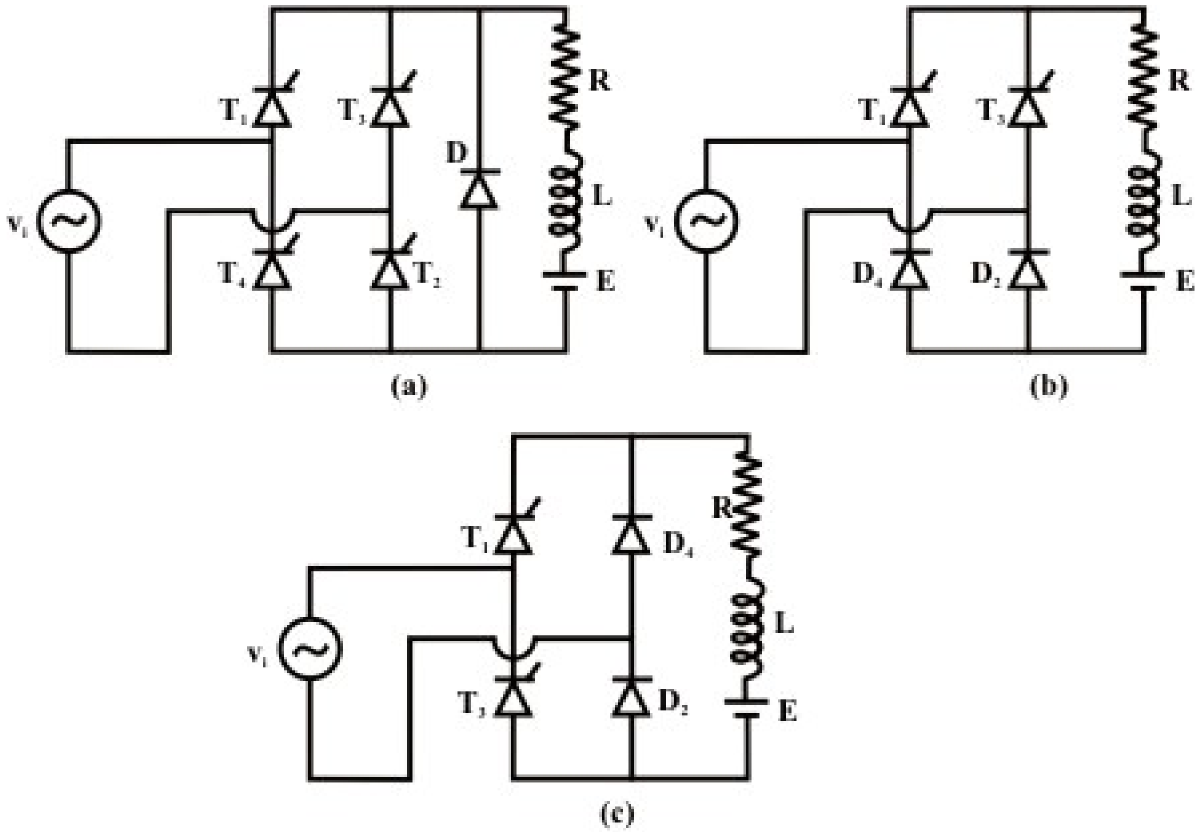


Fig. 11.1: Alternative circuits of single phase half controlled converter.
(a) fully controlled converter with load side free wheeling diode
(b) half controlled converter - alternative -1
(c) half controlled converter - alternative -2.

11.2 Operating principle of a single phase half controlled bridge converter

With reference of Fig 11.1 (b), it can be stated that for any load current to flow one device from the top group (T_1 or T_3) and one device from the bottom group must conduct. However, T_1 T_3 or D_2 D_4 cannot conduct simultaneously. On the other hand T_1 D_4 and T_3 D_2 conducts simultaneously whenever T_1 or T_3 are on and the output voltage tends to go negative. Therefore, there are four operating modes of this converter when current flows through the load. Of course it is always possible that none of the four devices conduct. The load current during such periods will be zero. The operating modes of this converter and the voltage across different devices during these operating modes are shown in the conduction table of Fig 11.2. This table has been prepared with reference to Fig 11.1 (b).

DEVICE / Mode	v_{T_1}	v_{T_3}	v_{D_2}	v_{D_4}	v_o
T_1D_2	0	$-v_i$	0	$-v_i$	v_i
T_1D_4	0	$-v_i$	v_i	0	0
T_3D_4	v_i	0	v_i	0	$-v_i$
T_3D_2	v_i	0	0	$-v_i$	0
NONE	$\frac{v_i - E}{2}$	$-\frac{v_i + E}{2}$	$\frac{v_i - E}{2}$	$-\frac{v_i + E}{2}$	E

Fig. 11.2: Conduction Table of single phase half controlled converter

It is observed that whenever D_2 conducts the voltage across D_4 is $-v_i$ and whenever D_4 conducts the voltage across D_2 is v_i. Since diodes can block only negative voltage it can be concluded that D_2 and D_4 conducts in the positive and the negative half cycle of the input supply respectively. Similar conclusions can be drawn regarding the conduction of T_1 and T_3. The operation of the converter can be explained as follows when T_1 is fired in the positive half cycle of the input voltage. Load current flows through T_1 and D_2. If at the negative going zero crossing of the input voltage load current is still positive it commutates from D_2 to D_4 and the load voltage becomes zero. If the load current further continuous till T_3 is fired current commutates from T_1 to T_3. This mode of conduction when the load current always remains above zero is called the continuous conduction mode. Otherwise the mode of conduction becomes discontinuous.

Exercise 11.1

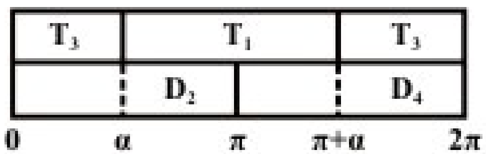
Fill in the blanks(s) with the appropriate word(s)

i. In a half controlled converter two ____________________ of a fully controlled converter are replaced by two ____________________.
ii. Depending on the positions of the ____________________ the half controlled converter can have ____________________ different circuit topologies.
iii. The input/output waveforms of the two different circuit topologies of a half controlled converter are ____________________ while the device ratings are ____________________.
iv. A half controlled converter has better output voltage ____________________ compared to a fully controlled converter.
v. A half controlled converter has improved input ____________________ compared to a fully controlled converter.

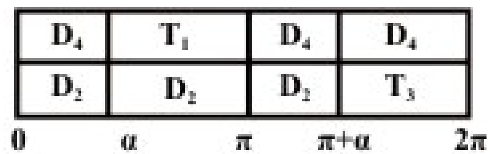
Answer: (i) thyristors, diodes; (ii) diodes, two; (iii) same, different; (iv) form factor; (v) power factor.

2. Find out an expression of the ration of the thyristor to diode RMS current ratings in the single phase half controlled converter topologies of Fig. 11.1(b) & (c). Assume ripple free continuous output current.

Answer



Conduction diagram of the circuit in Fig. 11.1(b).



Conduction diagram of the circuit in Fig. 11.1(c).

In the first conduction diagram the diodes and the thyristors conduct for equal periods, since the load current is constant. The ration of the thyristors to the diode RMS current ratings will be unity for the circuit of Fig 11.1 (b).

From the second conduction diagram the thyristors conduct for $\pi - \alpha$ radians while the diodes conduct for $\pi + \alpha$ radians. Since the load current is constant.

$$\frac{\text{Thyristor RMS current rating}}{\text{Diode RMS current rating}} = \sqrt{\frac{1-\alpha/\pi}{1+\alpha/\pi}}$$

in this case

11.2.1 Single phase half controlled converter in the continuous conduction mode

From the conduction table and the discussion in the previous section it can be concluded that the diode D_2 and D_4 conducts for the positive and negative half cycle of the input voltage waveform respectively. On the other hand T_1 starts conduction when it is fired in the positive half cycle of the input voltage waveform and continuous conduction till T_3 is fired in the negative half cycle. Fig. 11.3 shows the circuit diagram and the waveforms of a single phase half controlled converter supplying an R – L – E load.

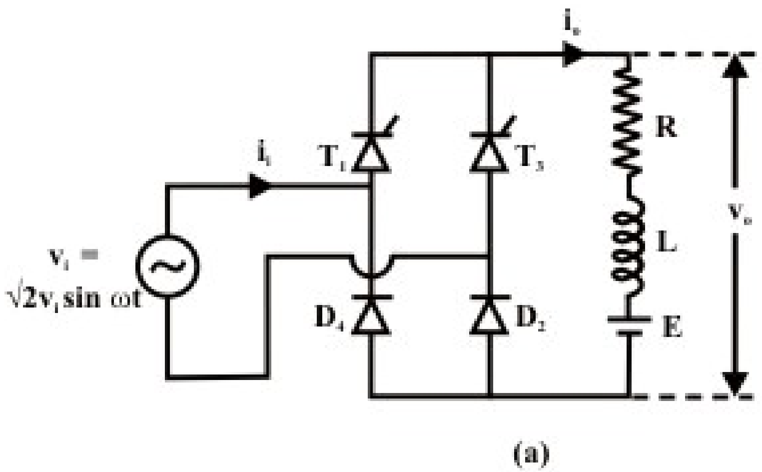
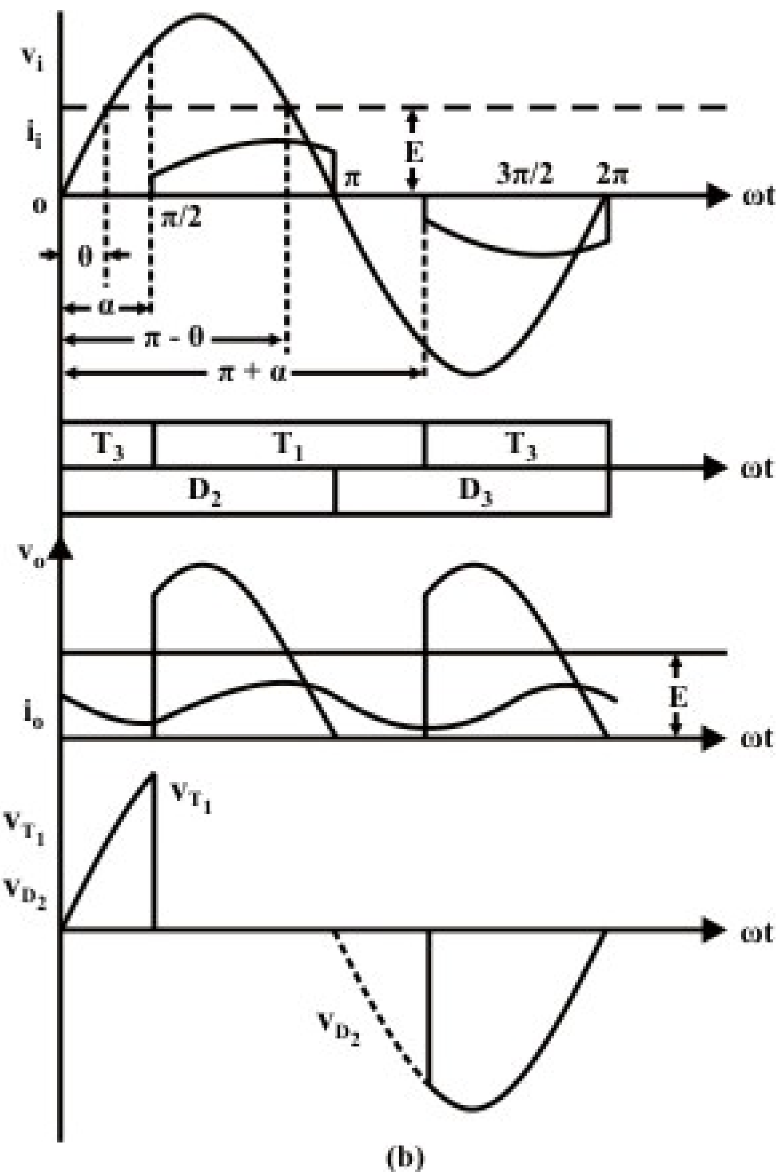


Fig. 11.3: Single phase half controlled converter in the continuous conduction mode
(a) Circuit diagram
(b) Waveforms



Referring to Fig 11.3 (b) T_1 D_2 starts conduction at $\omega t = \alpha$. Output voltage during this period becomes equal to v_i. At $\omega t = \pi$ as v_i tends to go negative D_4 is forward biased and the load current commutates from D_2 to D_4 and freewheels through D_4 and T_1. The output voltage remains clamped to zero till T_3 is fired at $\omega t = \pi + \alpha$. The T_3 D_4 conduction mode continues upto $\omega t = 2\pi$. Where upon load current again free wheels through T_3 and D_2 while the load voltage is clamped to zero.

From the discussion in the previous paragraph it can be concluded that the output voltage (hence the output current) is periodic over half the input cycle. Hence

$$V_{oav} = \frac{1}{\pi}\int_{o}^{\pi} v_o d\omega t = \frac{1}{\pi}\int_{\alpha}^{\pi} \sqrt{2}V_i \sin \omega t \, d\omega t = \frac{\sqrt{2}V_i}{\pi}(1+\cos\alpha) \qquad (11.1)$$

$$I_{ov} = \frac{V_{oav} - E}{R} = \frac{\sqrt{2}V_i}{\pi R}(1+\cos\alpha - \pi\sin\theta) \qquad (11.2)$$

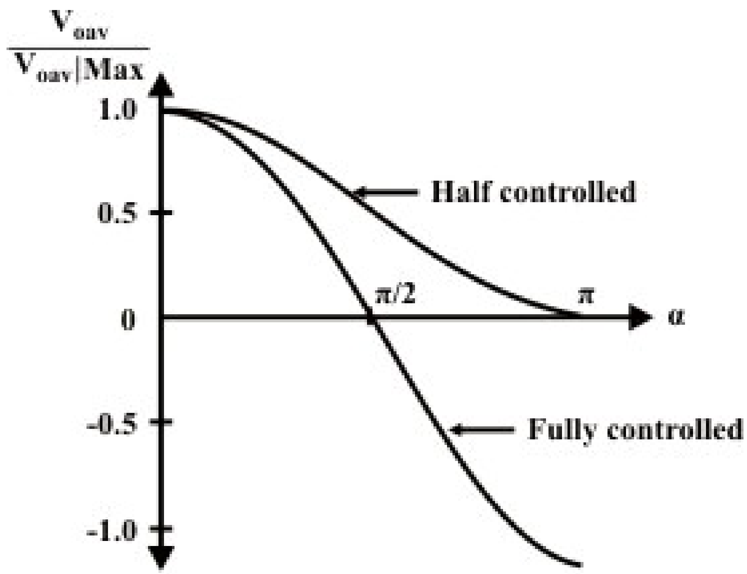


Fig. 11.4: Variation of average output voltage as a function of the firing angle (α)

Clearly in addition to the average component, the output voltage (and current) contains a large number of harmonic components. The minimum harmonic voltage frequency is twice the input supply frequency. Magnitude of the harmonic voltages can be found by Fourier series analysis of the load voltage and is left as an exercise.

The Fourier series representation of the load current can be obtained from the load voltage by applying superposition principle in the same way as in the case of a fully controlled converter.

However, the closed form expression of i_o can be found as explained next.

In the period $\alpha \le \omega t \le \pi$

$$L\frac{di_o}{dt} + Ri_o + E = \sqrt{2}V_i \sin \omega t \tag{11.3}$$

$$i_o = I_1 e^{-\frac{(\omega t-\alpha)}{\tan\varphi}} + \frac{\sqrt{2}V_i}{Z}\left[\sin(\omega t - \varphi) - \frac{\sin\theta}{\cos\varphi}\right] \tag{11.4}$$

Where $\sin\theta = \dfrac{E}{\sqrt{2}V_i}$; $Z = \sqrt{R^2 + \omega^2 L^2}$; $\tan\varphi = \dfrac{\omega L}{R}$

$$i_o\big|_\alpha = I_1 + \frac{\sqrt{2}V_i}{Z}\left[\sin(\alpha - \varphi) - \frac{\sin\theta}{\cos\varphi}\right] \tag{11.5}$$

$$i_o\big|_\pi = I_1 - \frac{(\pi - \alpha)}{\tan\varphi} + \frac{\sqrt{2}V_i}{Z}\left[\sin\varphi - \frac{\sin\theta}{\cos\varphi}\right] \tag{11.6}$$

In the period $\pi \le \omega t \le \pi + \alpha$

$$L\frac{di_o}{dt} + Ri_o + E = 0 \tag{11.7}$$

$$i_o = i_o\big|_{\pi} e^{-\frac{(\omega t-\pi)}{\tan\varphi}} - \frac{\sqrt{2}V_i}{Z}\frac{\sin\theta}{\cos\varphi}\left[1 - e^{-\frac{(\omega t-\pi)}{\tan\varphi}}\right] \tag{11.8}$$

$$\therefore \quad i_o = I_1 e^{-\frac{(\omega t-\alpha)}{\tan\varphi}} + \frac{\sqrt{2}V_i}{Z}\left[\sin\varphi\, e^{-\frac{(\omega t-\pi)}{\tan\varphi}} - \frac{\sin\theta}{\cos\varphi}\right] \tag{11.9}$$

$$\therefore \quad i_o\big|_{\pi+\alpha} = I_1 e^{-\frac{\pi}{\tan\varphi}} + \frac{\sqrt{2}V_i}{Z}\left[\sin\varphi\, e^{-\frac{\alpha}{\tan\varphi}} - \frac{\sin\theta}{\cos\varphi}\right] \tag{11.10}$$

Due to periodic operation

$$i_o\big|_{\alpha} = i_o\big|_{\pi+\alpha}$$

$$\therefore \quad I_1 = \frac{\sqrt{2}V_i}{Z}\;\frac{\sin(\varphi-\alpha) + \sin\varphi\, e^{-\frac{\alpha}{\tan\varphi}}}{1 - e^{-\frac{\pi}{\tan\varphi}}} \tag{11.11}$$

$\therefore$ For $\alpha \le \omega t \le \pi$

$$i_o = \frac{\sqrt{2}V_i}{Z}\left\{\left[\sin(\varphi-\alpha) + \sin\varphi e^{-\frac{\alpha}{\tan\varphi}}\right]\frac{e^{-\frac{(\omega t-\alpha)}{\tan\varphi}}}{1 - e^{-\frac{\pi}{\tan\varphi}}} + \sin(\omega t-\varphi) - \frac{\sin\theta}{\cos\varphi}\right\} \tag{11.12}$$

For $\pi \le \omega t \le \pi + \alpha$

$$i_o = \frac{\sqrt{2}V_i}{Z}\left\{\left[\sin(\varphi-\alpha) + \sin\varphi e^{-\frac{\alpha}{\tan\varphi}}\right]\frac{e^{-\frac{(\omega t-\alpha)}{\tan\varphi}}}{1 - e^{-\frac{\pi}{\tan\varphi}}} + \sin\varphi\, e^{-\frac{(\omega t-\pi)}{\tan\varphi}} - \frac{\sin\theta}{\cos\varphi}\right\} \tag{11.13}$$

The input current i_i is given by

$$\begin{aligned} i_i &= i_0 && \text{for } \alpha \le \omega t \le \pi \\ i_i &= -\,i_0 && \text{for } \pi + \alpha \le \omega t \le 2\pi \\ i_i &= 0 && \text{otherwise} \end{aligned} \tag{11.14}$$

However, it will be very difficult to find out the characteristic parameters of i_i using equation 11.14 since the expression of i_0 is considerably complex. Considerable simplification can however be obtained if the actual i_i waveform is replaced by a quasisquare wave current waveform with an amplitude of I_{oav} as shown in Fig 11.5.

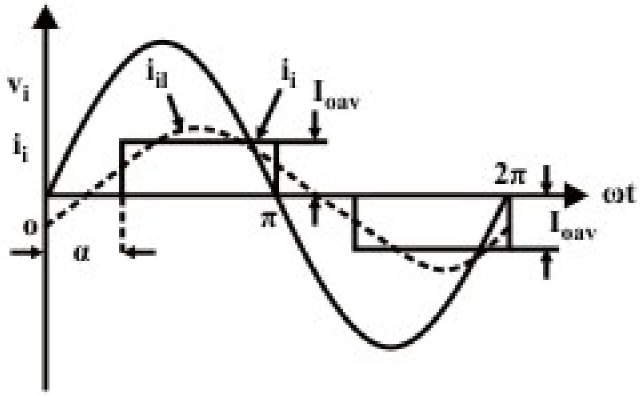


Fig. 11.5: Input current waveform of half controlled converters

From Fig 11.5

$$I_{iRMS} = \sqrt{1-\alpha/\pi}\, I_{oav} \tag{11.15}$$

The displacement factor = cos α/2 (11.16)

$$\therefore \quad V_i\, I_{i1} \cos{\alpha/2} = V_o I_{oav} = \frac{\sqrt{2}V_i}{\pi}(1+\cos\alpha)I_{OAV} \tag{11.17}$$

$$\therefore \quad I_{i1} = \frac{2\sqrt{2}}{\pi} I_{OAV} \cos{\alpha/2} \tag{11.18}$$

$$\therefore \quad \text{Distortion factor} = \frac{I_{i1}}{I_{iRMS}} = 2\sqrt{\frac{2}{\pi(\pi-\alpha)}}\cos{\alpha/2} \tag{11.19}$$

$$\therefore \quad \text{Power factor} = \text{displacement factor} \times \text{distortion factor}$$

$$= \frac{\sqrt{2}}{\sqrt{\pi(\pi-\alpha)}}(1+\cos\alpha) \tag{11.20}$$

Exercise 11.2

Fill in the blank(s) with the appropriate word(s).

i. In a half controlled converter the output voltage can not become ___________________ and hence it can not operate in the ___________________ mode.

ii. For the same firing angle and input voltage the half controlled converter gives ___________________ output voltage form factor compared to a fully controlled converter.

iii. For ripple-free continuous output current the input current displacement factor of a half controlled converter is given by ___________________.

iv. For the same supply and load parameters the output current form factor of a half controlled converter is ___________________ compared to a fully controlled converter.

v. The free wheeling operating mode of a half controlled converter helps to make the output current ___________________.

Answer: (i) negative, inverter; (ii) lower; (iii) $\cos\frac{\pi}{2}$; (iv) lower; (v) continuous.

2. A single phase half controlled converter is used to supply the field winding of a separately excited dc machine. With the rated armature voltage the motor operates at the rated no load speed for a fining angle α =0°. Find the value of α which will increase the motor no load speed by 30%. Neglect lasses and saturation. Assume continuous conduction.

Answer:

$$N_{\text{NO load}} \;\alpha\; 1/\phi_f \qquad \text{or} \quad \phi_f \;\alpha\; \frac{1}{N_{\text{NO load}}}$$

In order to increase $N_{\text{no load}}$ by 30% ϕ_f should be reduced by 23%. Therefore the applied field voltage must by 23%.

Now by (11.1)

$$V_f(\alpha) = V_f(\alpha = 0)\frac{1+\cos\alpha}{2}$$

$$\therefore\; 1 - \frac{1+\cos\alpha}{2} = \frac{1-\cos\alpha}{2} = 0.23$$

$$\therefore\; \alpha = 57.4^{o}$$

11.2.2 Single phase half controlled converter in the discontinuous conduction mode.

So far we have discussed the operating characteristics of a single phase half controlled converter in the continuous conduction mode without identifying the condition required to achieve it. Such a condition exists however and can be found by carefully examining the way this converter works.

Referring to Fig 11.3 (b), when T_1 is fired at ωt = α the output voltage (instantaneous value) is larger than the back emf. Therefore, the load current increases till v_o becomes equal to E again at ωt = π – θ. There, onwards the load current starts decreasing. Now if i_o becomes zero before T_3 is fired at ωt = π + α the conduction becomes discontinuous. So clearly the condition for continuous conduction will be

$$i_o\big|_{\omega t} = \alpha \geq 0 \qquad (11.21)$$

Which in conjunction with the equation (11.12) gives

$$\frac{\sin(\varphi-\alpha) + \sin\varphi\, e^{-\frac{\alpha}{\tan\varphi}}}{1 - e^{-\frac{\pi}{\tan\varphi}}} - \sin(\varphi-\alpha) \geq \frac{\sin\theta}{\cos\varphi}$$

$$\text{or} \qquad \frac{\sin(\varphi-\alpha)e^{-\frac{\pi}{\tan\varphi}} + \sin\varphi\, e^{-\frac{\alpha}{\tan\varphi}}}{1-e^{-\frac{\pi}{\tan\varphi}}} \geq \frac{\sin\theta}{\cos\varphi} \qquad (11.22)$$

If the condition in Eq. 11.22 is violated the conduction will become discontinuous. Clearly, two possibilities exist. In the first case the load current becomes zero before $\omega t = \pi$. In the second case i_o continuous beyond $\omega t = \pi$ but becomes zero before $\omega t = \pi + \alpha$. In both cases however, i_o starts from zero at $\omega t = \alpha$.

Fig. 11.6 shows the wave forms in these two cases.

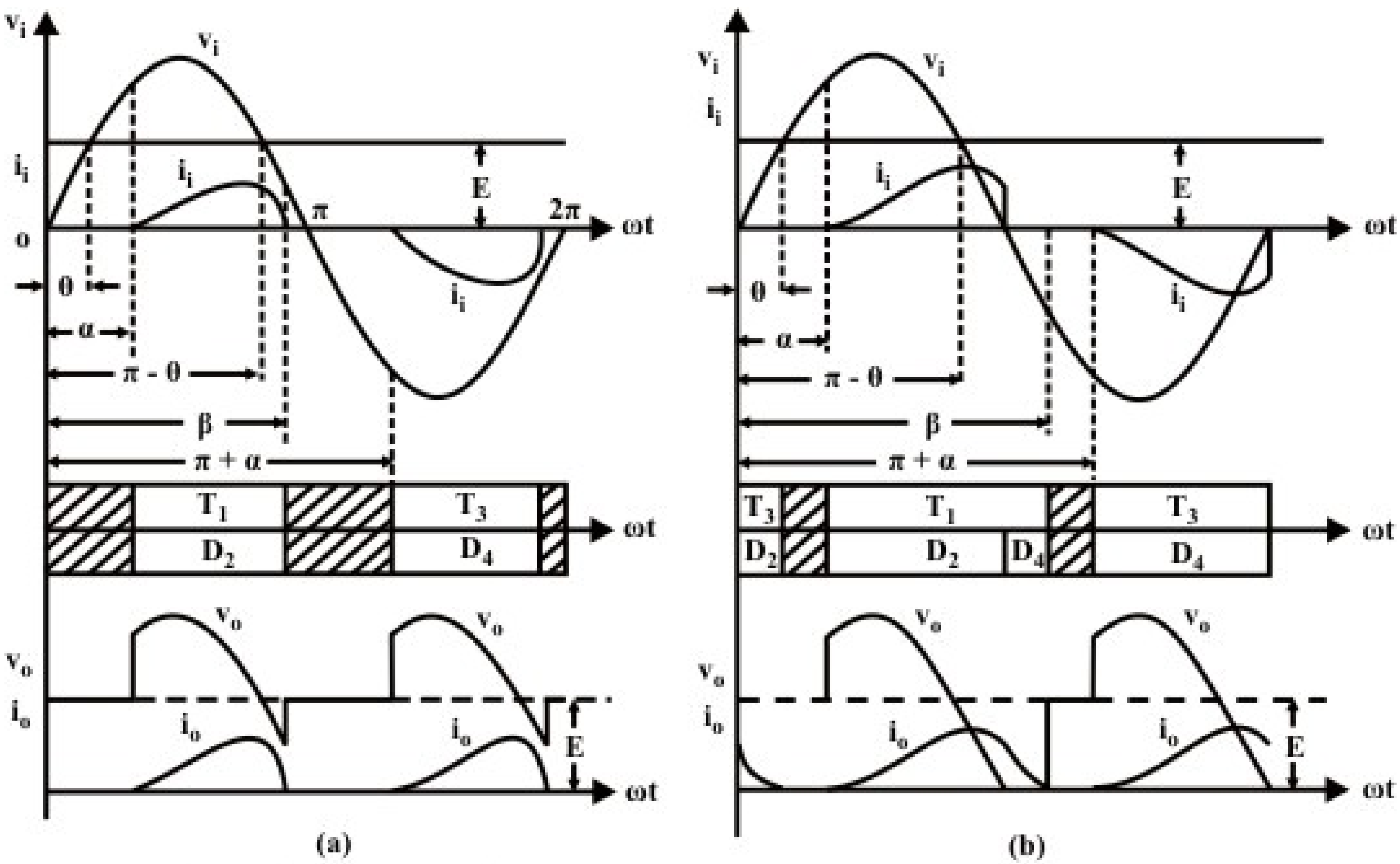


Fig. 11.6: Single phase half controlled converter in discontinuous conduction mode.
(a) $\pi - \theta \leq \beta \leq \pi$;
(b) $\pi \leq \beta \leq \pi + \alpha$

Of these two cases the second one will be analyzed in detail here. The analysis of the first case is left as an exercise.

For this case

$$\begin{aligned} v_o &= v_i && \text{for } \alpha \leq \omega t \leq \pi \\ v_o &= 0 && \text{for } \pi \leq \omega t \leq \beta \qquad (11.23) \\ v_o &= E && \text{for } \beta \leq \omega t \leq \pi + \alpha \end{aligned}$$

Therefore $$V_{OAV} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} v_o \, d\omega t$$

$$= \frac{1}{\pi}\left[\int_{\alpha}^{\pi}\sqrt{2}v_i \sin\omega t \, d\omega t + \int_{\beta}^{\pi+\alpha}\sqrt{2}v_i \sin\theta \, d\omega t\right]$$

$$= \frac{\sqrt{2}V_i}{\pi}\left[1+\cos\alpha+(\pi+\alpha-\beta)\sin\theta\right] \quad (11.24)$$

$$I_{OAV} = \frac{V_{OAV} - E}{R} = \frac{\sqrt{2}V_i}{\pi Z\cos\varphi}\left[1+\cos\alpha+(\alpha-\beta)\sin\theta\right] \quad (11.25)$$

$$V_{ORMS} = \frac{1}{\pi}\sqrt{\int_{\alpha}^{\pi+\alpha} v_o^2 d\omega t}$$

$$= \frac{1}{\pi}\left[\int_{\alpha}^{\pi} 2v_i^2 \sin^2\omega t \, d\omega t + \int_{\beta}^{\pi+\alpha} 2v_i^2 \sin^2\theta \, d\omega t\right]^{\frac{1}{2}}$$

$$= \frac{\sqrt{2}V_i}{\pi}\left[\frac{\pi-\alpha}{2} + (\pi+\alpha-\beta)\sin^2\theta + \frac{1}{4}\sin 2\alpha\right]^{\frac{1}{2}} \quad (11.26)$$

However I_{ORMS} cannot be computed directly from V_{ORMS}. For this the closed form expression for i_o has to be obtained. This will also help to find out an expression for the conduction angle β.

For $\alpha \le \omega t \le \pi$

$$\sqrt{2}V_i \sin\omega t = Ri_o + L\frac{di_o}{dt} + E \quad (11.27)$$

The general solution is given by

$$i_o = I_o \, e^{-\frac{(\omega t-\alpha)}{\tan\varphi}} + \frac{\sqrt{2}V_i}{Z}\sin(\omega t-\varphi) - \frac{\sqrt{2}V_i}{Z}\frac{\sin\theta}{\cos\varphi} \quad (11.28)$$

Where $Z = \sqrt{R^2+\omega^2L^2}$; $\tan\varphi = \omega L / R$; $E = \sqrt{2}V_i \sin\theta$

At $\omega t = \alpha$, $i_o = 0$

$$\therefore \quad I_o = \frac{\sqrt{2}V_i}{Z}\left[\frac{\sin\theta}{\cos\varphi} + \sin(\varphi-\alpha)\right] \quad (11.29)$$

$$\therefore \quad i_o = \frac{\sqrt{2}V_i}{Z}\left\{\left[\frac{\sin\theta}{\cos\varphi} + \sin(\varphi-\alpha)\right]e^{-\frac{\omega t-\alpha}{\tan\varphi}} + \sin(\omega t-\varphi) - \frac{\sin\theta}{\cos\varphi}\right\} \quad (11.30)$$

$$i_o \text{ at } \omega t = \pi = \frac{\sqrt{2}V_i}{Z}\left\{\left[\frac{\sin\theta}{\cos\varphi} + \sin(\varphi-\alpha)\right]e^{\frac{\alpha-\pi}{\tan\varphi}} + \sin\varphi - \frac{\sin\theta}{\cos\varphi}\right\} \quad (11.31)$$

For $\pi \le \omega t \le \beta$

$$O = Ri_o + L\frac{di_o}{dt} + E \quad (11.32)$$

$$\therefore \qquad i_o = I_1\, e^{-\frac{\omega t-\pi}{\tan\varphi}} - \frac{\sqrt{2}V_i}{Z}\frac{\sin\theta}{\cos\varphi} \tag{11.33}$$

$$i_o\big|_{\omega t=\pi} = I_1 - \frac{\sqrt{2}V_i}{Z}\frac{\sin\theta}{\cos\varphi}$$

$$= \frac{\sqrt{2}V_i}{Z}\left\{\left[\frac{\sin\theta}{\cos\varphi}+\sin(\varphi-\alpha)\right]e^{\frac{\alpha-\pi}{\tan\varphi}} + \sin\varphi - \frac{\sin\theta}{\cos\varphi}\right\} \tag{11.34}$$

$$\therefore \qquad I_1 = \frac{\sqrt{2}V_i}{Z}\left\{\left[\frac{\sin\theta}{\cos\varphi}+\sin(\varphi-\alpha)\right]e^{\frac{\alpha-\pi}{\tan\varphi}} + \sin\varphi\right\} \tag{11.35}$$

$$\therefore \qquad i_o = \frac{\sqrt{2}V_i}{Z}\left\{\left[\frac{\sin\theta}{\cos\varphi}+\sin(\varphi-\alpha)\right]e^{-\frac{\omega t-\alpha}{\tan\varphi}} + \sin\varphi e^{-\frac{\omega t-\pi}{\tan\varphi}} - \frac{\sin\theta}{\cos\varphi}\right\} \tag{11.36}$$

Equations (11.30) and (11.36) gives closed from expression of i_o in this conduction mode. To find out β we note that at $\omega t = \beta$, $i_o = 0$. So from equation (11.36)

$$\left[\frac{\sin\theta}{\cos\varphi}+\sin(\varphi-\alpha)\right]e^{\frac{\alpha-\beta}{\tan\varphi}} + \sin\varphi\, e^{\frac{\pi-\beta}{\tan\varphi}} - \frac{\sin\theta}{\cos\varphi} = 0 \tag{11.37}$$

or

$$\frac{\sin\theta}{\cos\varphi}e^{\frac{\beta}{\tan\varphi}} = \sin\varphi\, e^{\frac{\pi}{\tan\varphi}} + \sin(\varphi-\alpha)\, e^{\frac{\alpha}{\tan\varphi}} + \frac{\sin\theta}{\cos\varphi}e^{\frac{\alpha}{\tan\varphi}} \tag{11.38}$$

Given the values of φ, θ and α the value of β can be obtained from equation 11.38.

Exercise 11.3 (After section 11.2.2)

Fill in the blank(s) with the appropriate word(s).

i. At the boundary between continuous and discontinuous conduction the value of the output current at $\omega t = \alpha$ is ___________________.

ii. The output voltage and current waveform of a single phase fully controlled and half controlled converter will be same provided the extinction angle β is less than ___________________.

iii. For the same value of the firing angle the average output voltage of a single phase half controlled converter is ___________________ in the discontinuous conduction mode compared to the continuous conduction mode.

iv. Single phase half controlled converters are most suitable for loads requiring ___________________ voltage and current.

Answer: (i) zero; (ii) π; (iii) higher; (iv) unidirectional.

2. A single phase half controlled converter charges a 48v 50Ah battery from a 50v, 50Hz single phase supply through a 50mH line inductor. The battery has on interval resistance of 0.1Ω. The

firing angle of the converter is adjusted such that the battery is charged at C/5 rate when it is fully discharged at 42 volts. Find out whether the conduction will be continuous or discontinuous at this condition. Up to what battery voltage will the conduction remain continuous? If the charging current of the battery is to become zero when it is fully charged at 52 volts what should be the value of the firing angle.

Answer: From the given data assuming continuous conduction the output voltage of the converter to charge the battery at C/5 (10 Amps) rate will be

$$V_o = E + I_b r_b = 42 + 0.1 \times 10 = 43\text{volts}$$

$$\therefore\ \alpha = 24.43^o$$

$$\phi = \tan^{-1}\frac{\omega L}{R} = 89.63^o,\ \ \tan\phi = 157.08,\ \ \sin\phi = 0.99998\ \ \cos\phi = 6.3 \times 10^{-3}$$

Putting these values in equation (11.22) one finds that the conduction will be continuous.

The conduction will remain continuous till

$$\sin\theta = \frac{E}{\sqrt{2}v_i} = \frac{\cos\phi\ \sin(\phi-\alpha)e^{-\pi/\tan\phi} + \frac{1}{2}\sin 2\phi\ e^{-\alpha/\tan\phi}}{1 - e^{-\pi/\tan\phi}}$$

From the given value this gives.

$$E = \sqrt{2} \times 50 \times 0.606 = 42.8V$$

At E = 52 volts i_o is zero. Therefore

$$\sqrt{2}V_i \sin\alpha = E = 52$$

$$\therefore\ \alpha = 180^o - \frac{\sin 52}{\sqrt{2} \times 50} = 132.66^o$$

References

[1] "Power Electronics"; P.C. Sen; Tata McGraw Hill Publishing Company Limited 1995.

[2] "Power Electronics, circuits, devices and applications"; Second Edition; Muhammad H. Rashid; Prentice – Hall of India; 1994.

[3] "Power Electronics, converters, applications and design"; Third Edition; Mohan, Undeland, Robbins; John Wiley and Sons Inc., 2003.

Lesson Summary

- Single phase half controlled converters are obtained from fully controlled converters by replacing two thyristors by two diodes.
- Two thyristors of one phase leg or one group (top or bottom) can be replaced resulting in two different topologies of the half controlled converter. From the operational point of view these two topologies are identical.
- In a half controlled converter the output voltage does not become negative and hence the converter cannot operate in the inverter mode.
- For the same firing angle and input voltage the half controlled converter in the continuous conduction mode gives higher output voltage compared to a fully controlled converter.
- For the same input voltage, firing angle and load parameters the half controlled converter has better output voltage and current form factor compared to a fully controlled converter.
- For the same firing angle and load current the half controlled converter in the continuous conduction mode has better input power factor compared to a fully controlled converter.
- Half controlled converters are most favored in applications requiring unidirectional output voltage and current.

Practice Problems and Answers

Q1. The thyristor T_3 of Fig 1.1(b) fails to turn on at the desired instant. Describe how this circuit will work in the presence of the fault.

Q2. A single phase half controlled converter is used to boost the no load speed of a separately excited dc machine by weakening its field supply. At $\alpha = 0°$ the half controlled converter produces the rated field voltage. If the field inductance is large enough to make the field current almost ripple face what will be the input power factor when the dc motor no load speed is bossed to 150%?

Q3. A single phase half controlled converter supplies a 220V, 1500rpm, 20A dc motor from a 230V 50HZ single phase supply. The motor has a armature resistance of 1.0Ω and inductance of 50mH. What will be the operating modes and torques for $\alpha = 30°$; and speed of 1400 RPM.

Answer to practice problems

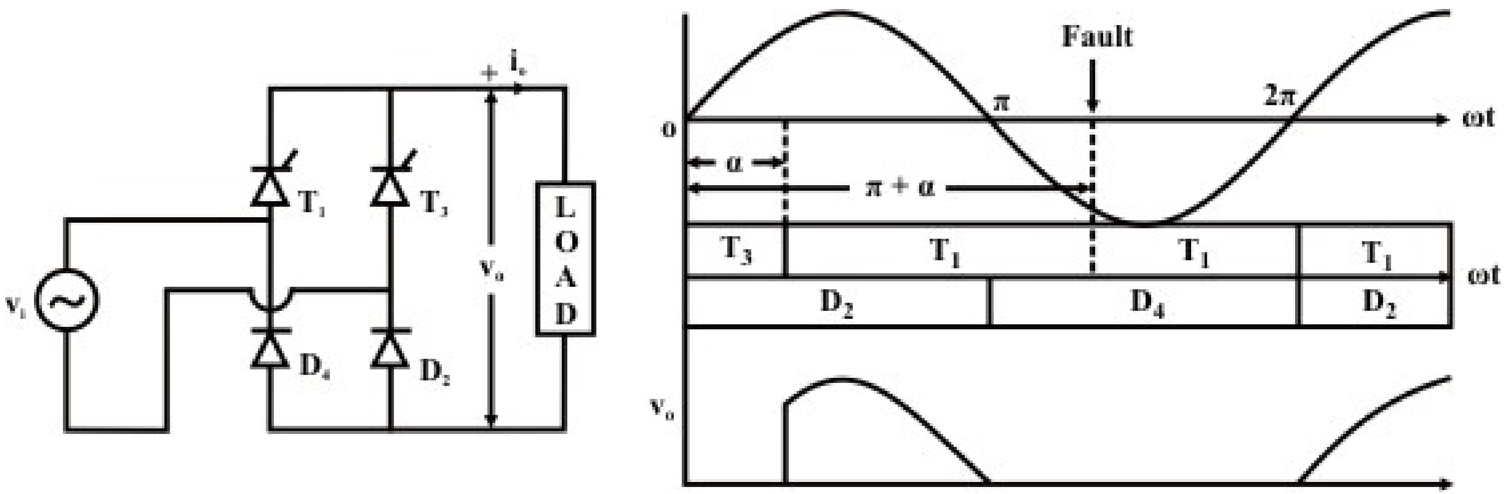


Figure above explains the operation of the circuit following the fault. T_1 is tired at $\omega t = \alpha$ and the load current commutates from T_3 to T_1. The conduction periods T_1 D_2 & T_1 D_4 commences as usual. However at $\omega t = \pi + \alpha$ when T_3 is fired it fails to turn ON and as a consequences T_1 does not commutate. Now if the load is highly inductive T_1 D_4 will continue to conduct till $\omega t = 2\pi$ and the load voltage will be clamped to zero during this period.

However, since T_1 does not stop conduction fining angle control on it is lost after words. Hence T_1 D_2 conduction period starts right after $\omega t = 2\pi$ instead of at $\omega t = 2\pi + \alpha$. Thus the full positive half cycle of supply voltage is applied across the load followed by a entire half cycle of zero voltage. Thus the load voltage becomes a half wave rectified sine wave and voltage control through fining angle is last. This is the effect of the fault.

[Note: This phenomenon is known as "half cycle brusting". It can be easily verified that this possibility does not existion the circuit shown in Fig 11.1 (c)]

2. For a separately excited dc motor

$$\omega_{\text{NO load}} \ \alpha \frac{1}{\phi_f} \ \alpha \ \frac{1}{V_f}$$

$$\therefore \ V_f = \frac{\text{Vf rated}}{1.5} \text{ for boosting no load speed by 150\%}$$

$$\text{but } \frac{\text{Vf}}{V_f \text{ rated}} = \frac{1+\cos\alpha}{2} = \frac{1}{1.5}$$

$$\therefore \ \alpha = 70.53^{\circ}$$

using equation 11.20 the power factor will be 0.77.

3. From the given data, $\tan\phi = \frac{\omega L}{R} = 15.7,\ \phi = 86.36^{o}$ $\sin\theta = \frac{E}{\sqrt{2}V_i} = \frac{14}{15}\times\frac{220-20\times1.0}{\sqrt{2}\times230} = 0.578$ substituting these values in equation 11.22 it can be conducted that the conduction is continuous

$$\therefore\ V_a = 193.2V,\ E = 186.7V$$

$$\therefore\ I_a = \frac{V_a - E}{r_a} = 6.53A$$

$\therefore$ Motor torque will be $\frac{6.53}{20}\times100 = 32.67\%$ of full load torque.

Source:http://www.nptel.ac.in/courses/Webcourse-contents/IIT%20Kharagpur/Power%20Electronics/PDF/L-11(DK)(PE)%20((EE)NPTEL).pdf