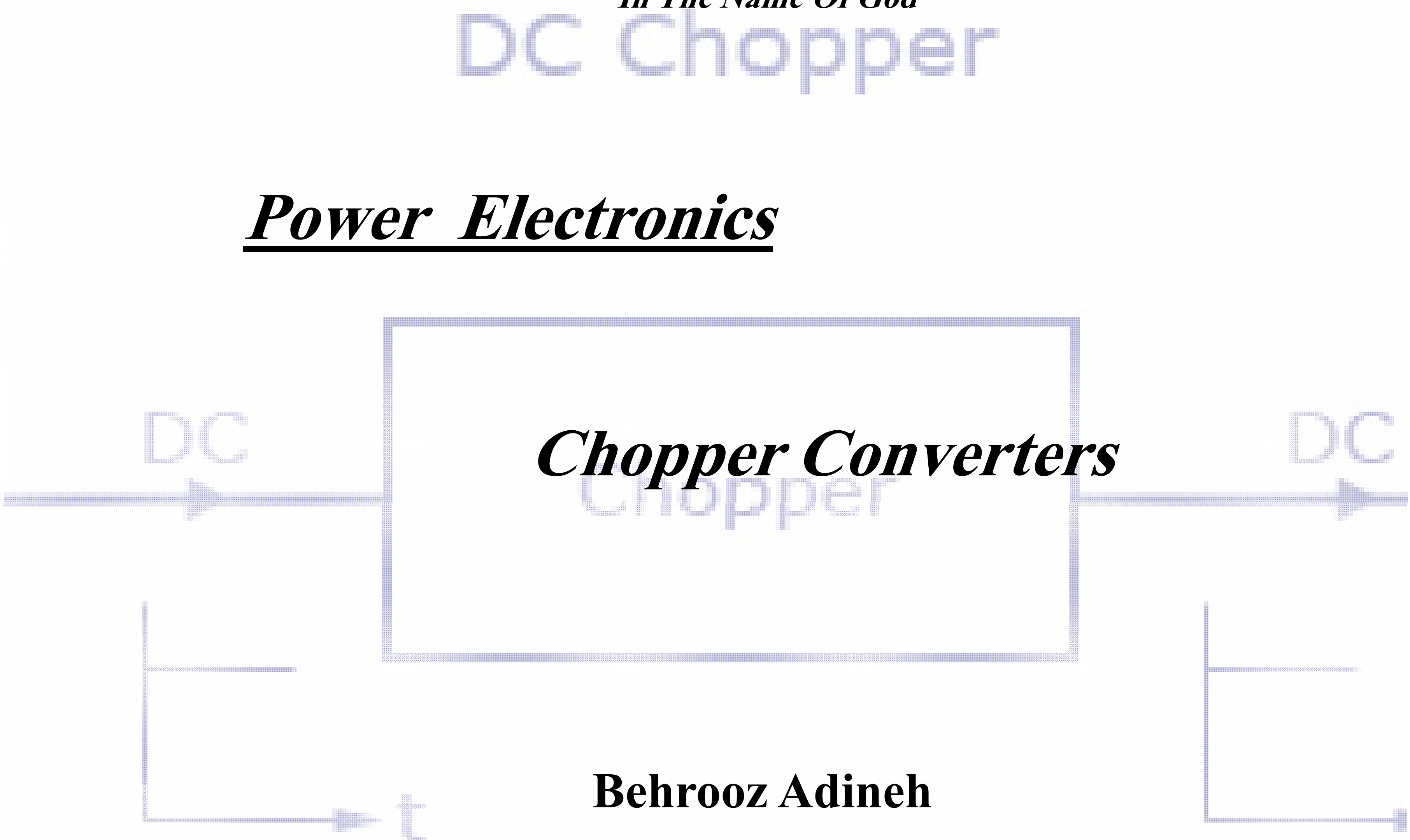
In The Name Of God

Power Electronics



Chopper Converters

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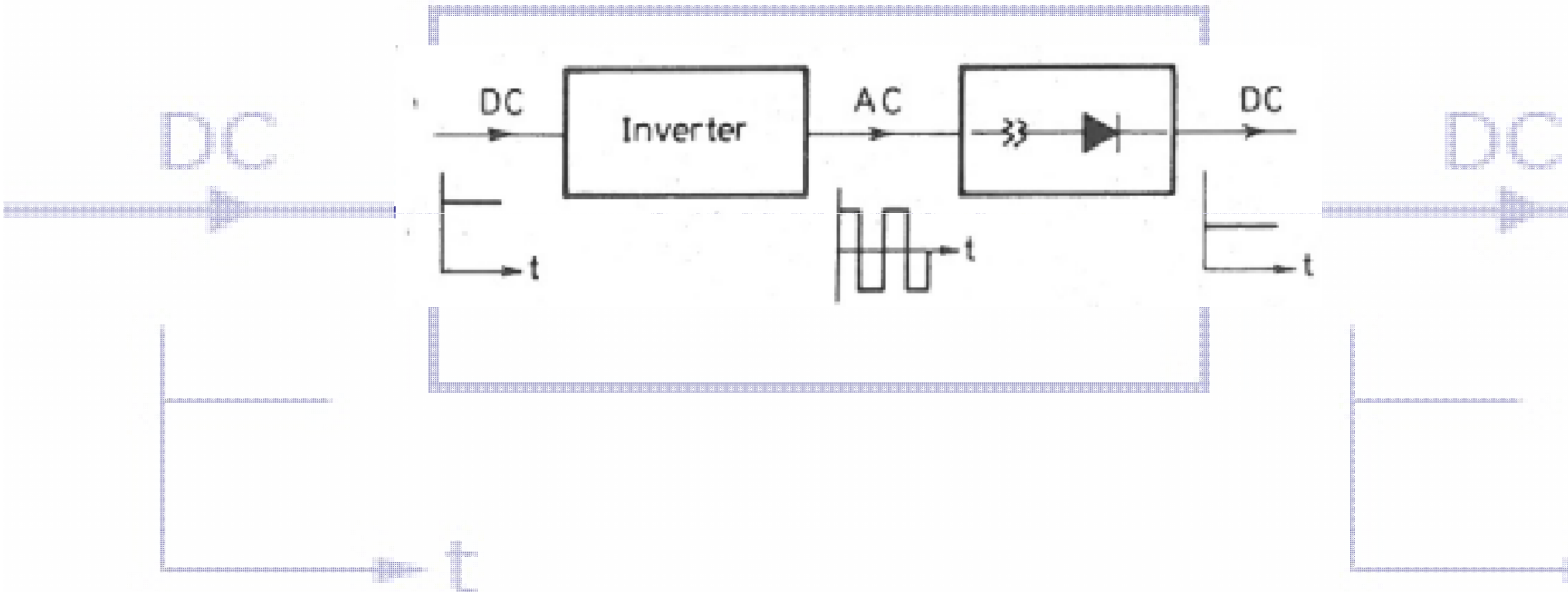
AC Link Chopper.

In the ac link chopper, dc is first converted to ac by an inverter (dc to ac converter). AC is then stepped-up or stepped-down by a transformer which is then converted back to dc by a diode rectifier Fig. As the conversion is in two stagés, dc to ac and then ac to dc, ac link chopper is costly, bulky and less efficient.



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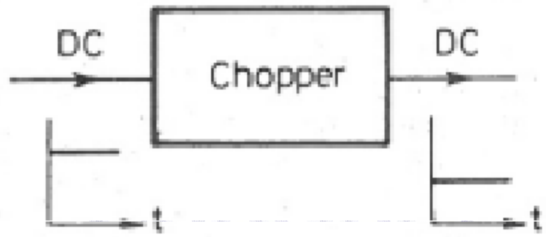
DC Chopper.

DC Chopper

A chopper is a static device that converts fixed dc input voltage to a variable dc output voltage directly Fig. A chopper may be thought of as dc equivalent of an ac transformer since they behave in an identical manner. As choppers involve one stage conversion, these are more efficient



DC → DC

Chopper systems offer smooth control, high efficiency, fast response and regeneration.

The power semiconductor devices used for a chopper circuit can be power BJT, power MOSFET, GTO or force-commutated thyristor.

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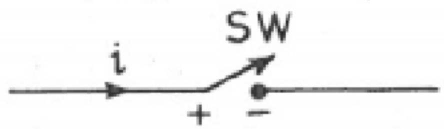
When the switch is off, no current can flow. When the switch is on, current flows in the direction of arrow only. The power semiconductor devices have on-state voltage drops of 0.5 V to 2.5 V across them. For the sake of simplicity, this voltage drop across these devices is neglected.

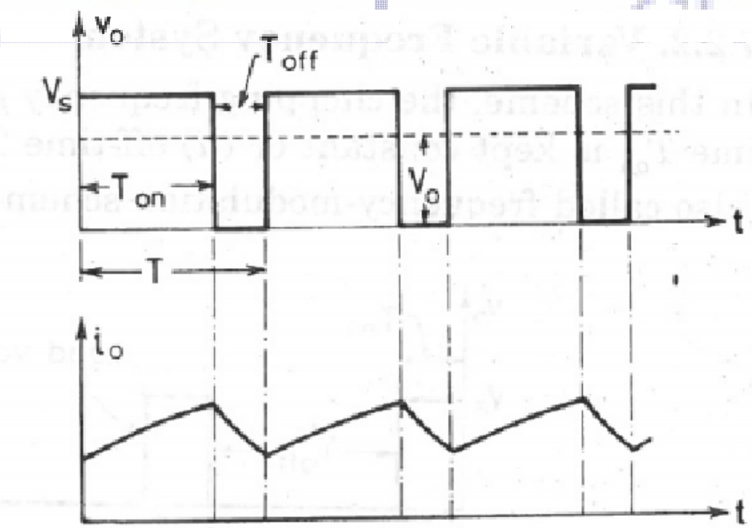


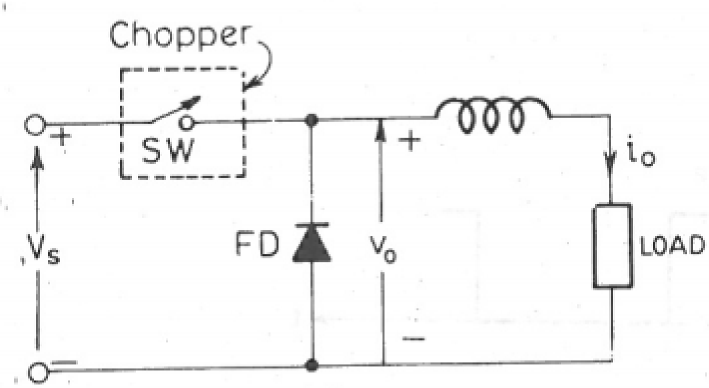
As stated above, a chopper is dc equivalent to an ac transformer having continuously variable turns ratio. Like a transformer, a chopper can be used to step down or step up the fixed dc input voltage. As step-down dc choppers are more common, a dc chopper, or chopper, in this book would mean a step-down dc chopper unless stated otherwise.

PRINCIPLE OF CHOPPER OPERATION

A chopper is a high speed on/off semiconductor switch. It connects source to load and disconnects the load from source at a fast speed. In this manner, a chopped load voltage as shown in Fig. is obtained from a constant dc supply of magnitude V_s. In Fig. chopper is represented by a switch SW inside a dotted rectangle, which may be turned-on or turned-off as desired. For the sake of highlighting the principle of choper operation, the circuitry used for controlled the on, off periods of this switch is not shown. During the period

T_{on}, chopper is on and load voltage is equal to source voltage V_s.





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During the interval T_{off}, chopper is off, load current flows through the freewheeling diode *FD*. As a result, load terminals are short circuited by *FD* and load voltage is therefore zero during T_{off}. In this manner, a chopped dc voltage is produced at the load terminals. The load current as shown in Fig. is continuous. From Fig. , average load voltage V_0 is given by

$$V_0 = \frac{T_{on}}{T_{on} + T_{off}} V_s = \frac{T_{on}}{T} V = \alpha V_s$$

where T_{on} = on–time ; T_{off} = off–time

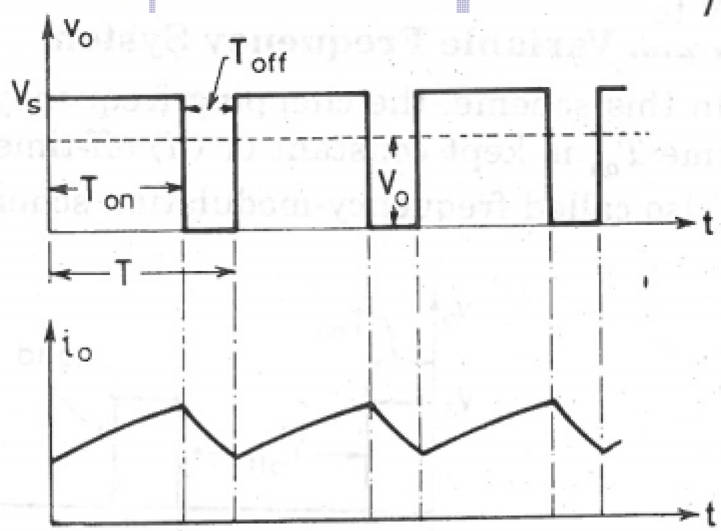
$T = T_{on} + T_{off}$ = chopping period

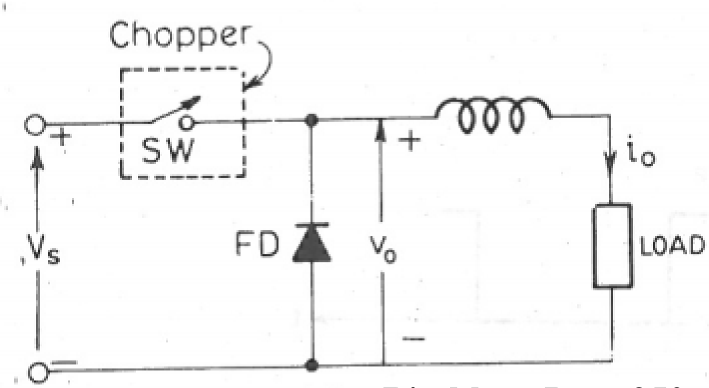
$\alpha = \frac{T_{on}}{T}$ = duty cycle

Thus load voltage can be controlled by varying duty cycle α. Eq. shows that load voltage is independent of load current. Eq. can also be written as

$$V_0 = f \cdot T_{on} \cdot V_s$$

$$f = \frac{1}{T} = \text{chopping frequency}$$





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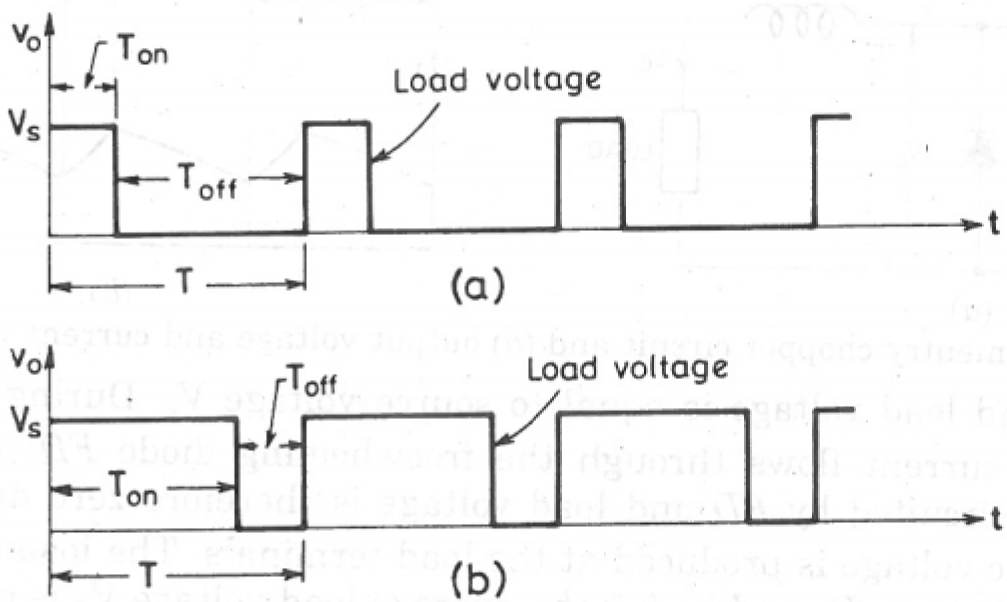
CONTROL STRATEGIES

It is seen from Eq. that average value of output voltage V_0 can be controlled through α by opening and closing the semiconductor switch periodically. The various control strategies for varying duty cycle α are as follows :

Constant Frequency System

In this scheme, the on-time T_{on} is varied but chopping frequency f (or chopping period T) is kept constant. Variation of T_{on} means adjustment of pulse width, as such this scheme is also called *pulse-width-modulation scheme*. This scheme has also been referred to as *time-ratio control* (TRC) by some authors.

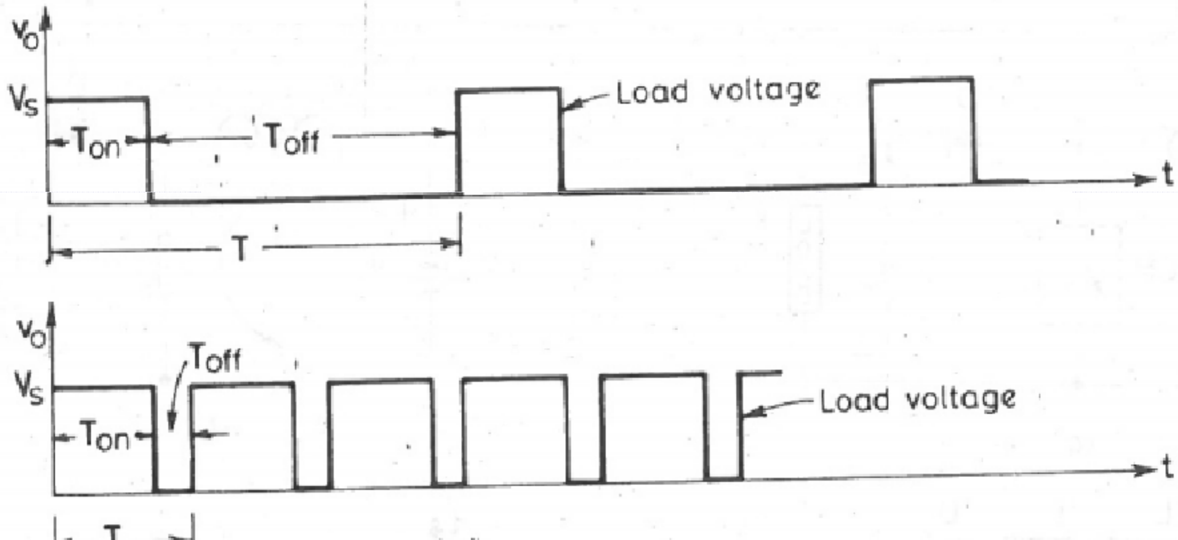
Fig. illustrates the principle of pulse-width modulation. Here chopping period T is constant. In Fig. (*a*), $T_{on} = \frac{1}{4} T$ so that $\alpha = 0.25$ or $\alpha = 25\%$. In Fig. (*b*), $T_{on} = \frac{3}{4} T$ so that $\alpha = 0.75$ or 75%. Ideally α can be varied from zero to infinity. Therefore output voltage V_0 can be varied between zero and source voltage V_s.



Variable Frequency System

In this scheme, the chopping frequency f (or chopping period T) is varied and either (*i*) on-time T_{on} is kept constant or (*ii*) off-time T_{off} is kept constant. This method of controlling α is also called frequency-modulation scheme.

Fig. illustrates the principle of frequency modulation. In Fig. ' (*a*), T_{on} is kept constant but T is varied. In the upper diagram of Fig. (*a*), $T_{on} = \frac{1}{4} T$ so that $\alpha = 0.25$. In the lower diagram of Fig. ' (*a*), $T_{on} = \frac{3}{4} T$ so that $\alpha = 0.75$. In Fig. (*b*), T_{off} is kept constant



(a)

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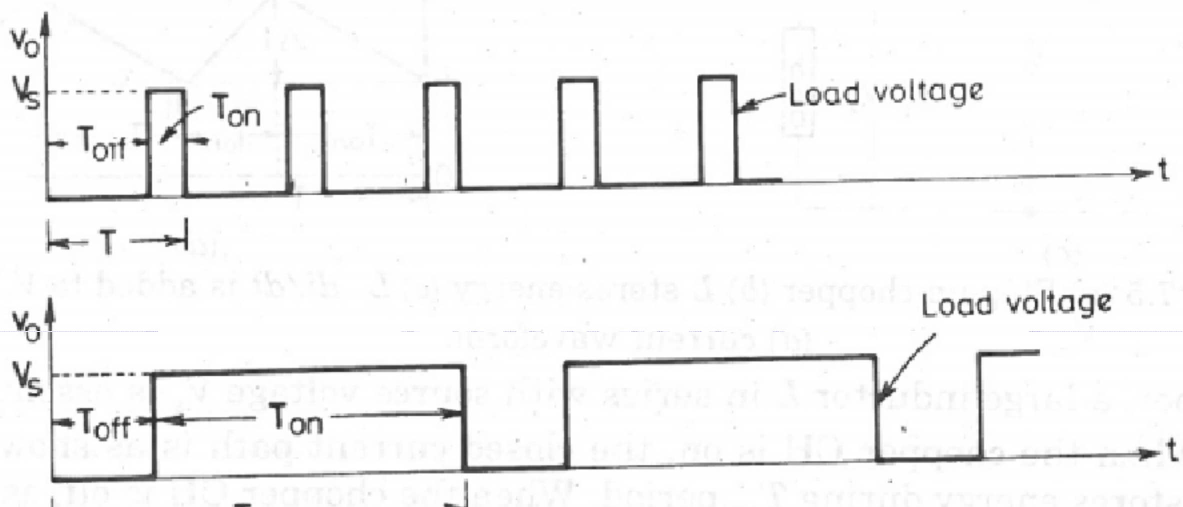
the lower diagram of Fig. ' (*a*), $T_{on} = \frac{3}{4}T$ so that $\alpha = 0.75$. In Fig. (*b*), T_{off} is kept constant and T is varied. In the upper diagram of this figure, $T_{on} = \frac{1}{4}T$ so that $\alpha = 0.25$ and in the lower diagram $T_{on} = \frac{3}{4}T$ so that $\alpha = 0.75$.



(b)

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Frequency modulation scheme has some disadvantages as compared to pulse-width modulation scheme. These are as under :

(*i*) The chopping frequency has to be varied over a wide range for the control of output voltage in frequency modulation. Filter design for such wide frequency variation is, therefore, quite difficult.

(*ii*) For the control of α, frequency variation would be wide. As such, there is a possibility of interference with signalling and telephone lines in frequency modulation scheme.

(*iii*) The large off-time in frequency modulation scheme may make the load current discontinuous which is undesirable.

It is seen from above that constant frequency (*PWM*) scheme is better than variable frequency scheme. *PWM* technique has, however, a limitation. In this technique, T_{on} cannot be reduced to near zero for most of the commutation circuits used in choppers. As such, low range of α control is not possible in *PWM*. This can, however, be achieved by increasing the chopping period (or decreasing the copping frequency) of the chopper.

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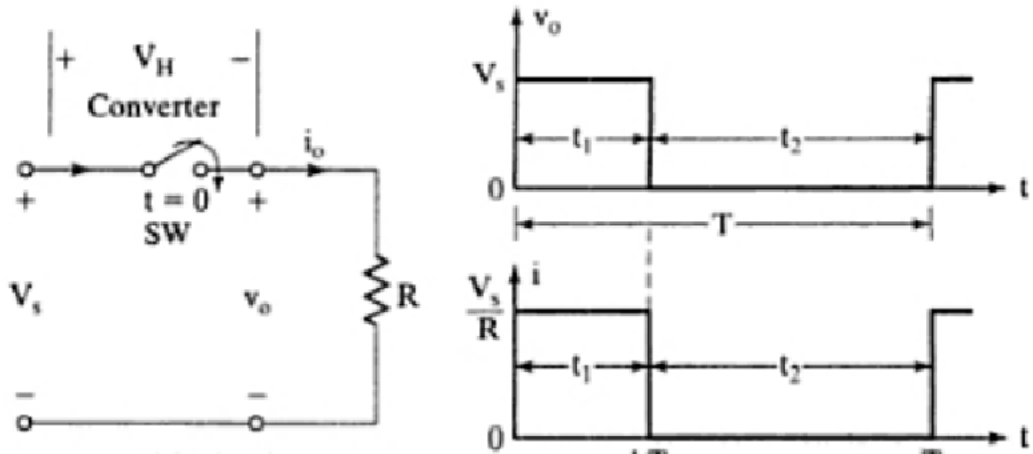
PRINCIPLE OF STEP-DOWN OPERATION



(a) Circuit

(b) Waveforms

The average output voltage is given by

$$V_a = \frac{1}{T}\int_0^{t_1} v_0\, dt = \frac{t_1}{T} V_s = f t_1 V_s = k V_s$$

and the average load current, $I_a = V_a/R = kV_s/R$,

where T is the chopping period;
$k = t_1/T$ is the duty cycle of chopper;
f is the chopping frequency.

The rms value of output voltage is found from

$$V_o = \left(\frac{1}{T}\int_0^{kT} v_0^2\, dt\right)^{1/2} = \sqrt{k}\, V_s$$

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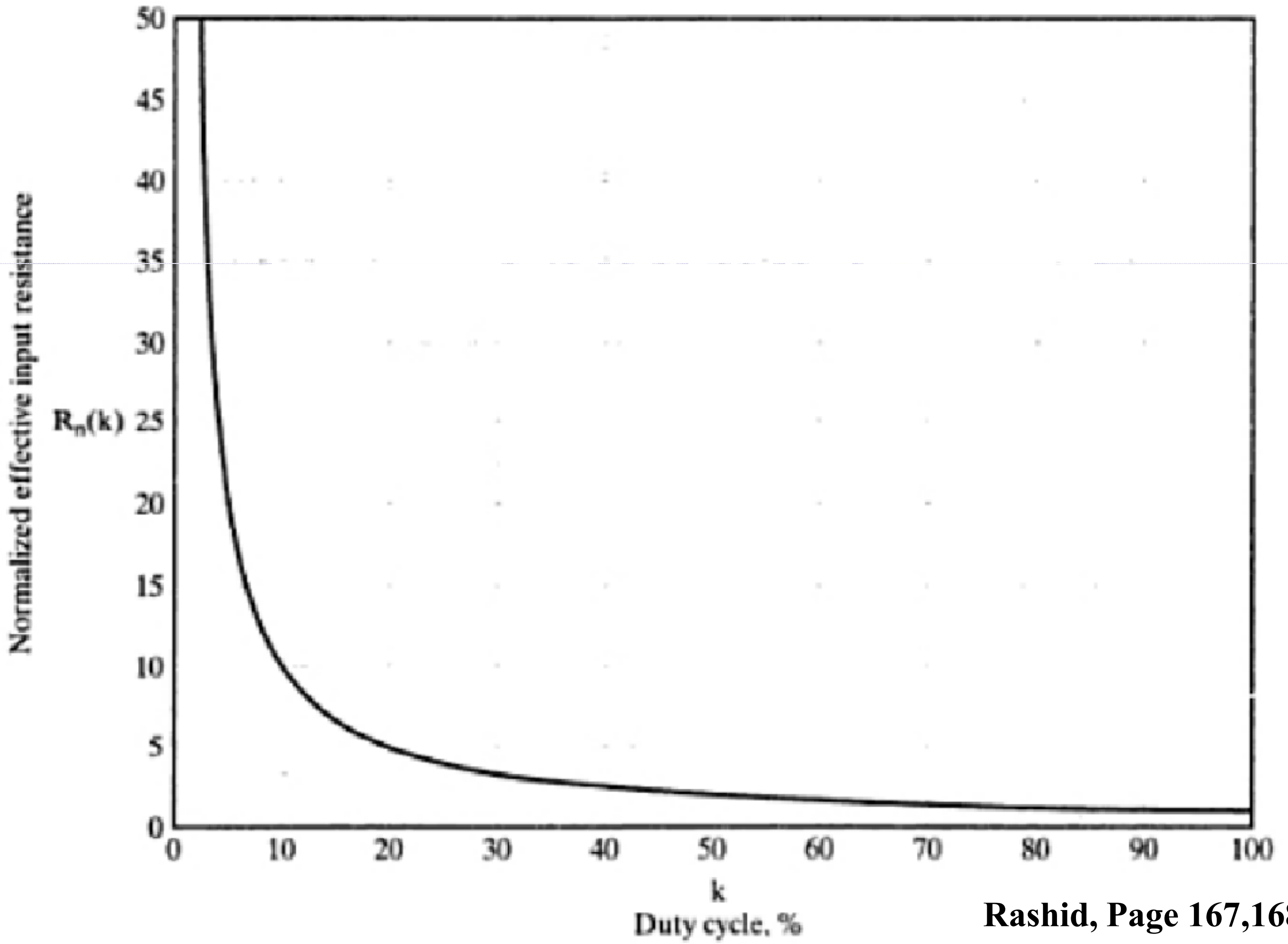
Assuming a lossless converter, the input power to the converter is the same as the output power and is given by

$$P_i = \frac{1}{T}\int_0^{kT} v_0 i \, dt = \frac{1}{T}\int_0^{kT} \frac{v_0^2}{R} dt = k\frac{V_s^2}{R}$$

The effective input resistance seen by the source is

$$R_i = \frac{V_s}{I_a} = \frac{V_s}{kV_s/R} = \frac{R}{k}$$



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Example Finding the Performances of a Dc–Dc Converter

The dc converter in Figure has a resistive load of $R = 10\ \Omega$ and the input voltage is $V_s = 220$ V. When the converter switch remains on, its voltage drop is $v_{ch} = 2$ V and the chopping frequency is $f = 1$ kHz. If the duty cycle is 50%, determine (a) the average output voltage V_a, (b) the rms output voltage V_o, (c) the converter efficiency, (d) the effective input resistance R_i of the converter, and (e) the rms value of the fundamental component of output harmonic voltage.

Solution

$V_s = 220$ V, $k = 0.5$, $R = 10\ \Omega$, and $v_{ch} = 2$ V.

a. From Eq. (5.1), $V_a = 0.5 \times (220 - 2) = 109$ V.

b. From Eq. (5.2), $V_o = \sqrt{0.5} \times (220 - 2) = 154.15$ V.

c. The output power can be found from

$$P_o = \frac{1}{T}\int_0^{kT} \frac{v_0^2}{R}\,dt = \frac{1}{T}\int_0^{kT} \frac{(V_s - v_{ch})^2}{R}\,dt = k\frac{(V_s - v_{ch})^2}{R}$$

$$= 0.5 \times \frac{(220 - 2)^2}{10} = 2376.2 \text{ W}$$

The input power to the converter can be found from

$$P_i = \frac{1}{T}\int_0^{kT} V_s i\,dt = \frac{1}{T}\int_0^{kT} \frac{V_s(V_s - v_{ch})}{R}\,dt = k\frac{V_s(V_s - v_{ch})}{R}$$

$$= 0.5 \times 220 \times \frac{220 - 2}{10} = 2398 \text{ W}$$

The converter efficiency is

$$\frac{P_o}{P_i} = \frac{2376.2}{2398} = 99.09\%$$

d. From Eq. (5.4), $R_i = 10/0.5 = 20\ \Omega$.

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e. The output voltage as shown in Figure can be expressed in a Fourier series as

$$v_o(t) = kV_s + \frac{V_s}{n\pi}\sum_{n=1}^{\infty} \sin 2n\pi k \cos 2n\pi f t$$

$$+ \frac{V_s}{n\pi}\sum_{n=1}^{\infty}(1 - \cos 2n\pi k)\sin 2n\pi f t$$

The fundamental component (for $n = 1$) of output voltage harmonic can be determined from Eq. as

$$v_1(t) = \frac{V_s}{\pi}[\sin 2\pi k \cos 2\pi f t + (1 - \cos 2\pi k)\sin 2\pi f t]$$

$$= \frac{220 \times 2}{\pi}\sin(2\pi \times 1000t) = 140.06 \sin(6283.2t)$$

and its root-mean-square (rms) value is $V_1 = 140.06/\sqrt{2} = 99.04$ V.

Note: The efficiency calculation, which includes the conduction loss of the converter, does not take into account the switching loss due to turn-on and turn-off of practical converters. The efficiency of a practical converter varies between 92 and 99%.

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Generation of Duty Cycle

The duty cycle k can be generated by comparing a dc reference signal v_r with a sawtooth carrier signal v_{cr}. This is shown in Figure , where V_r is the peak value of v_r, and V_{cr} is the peak value of v_{cr}. The reference signal v_r is given by

$$v_r = \frac{V_r}{T}t$$

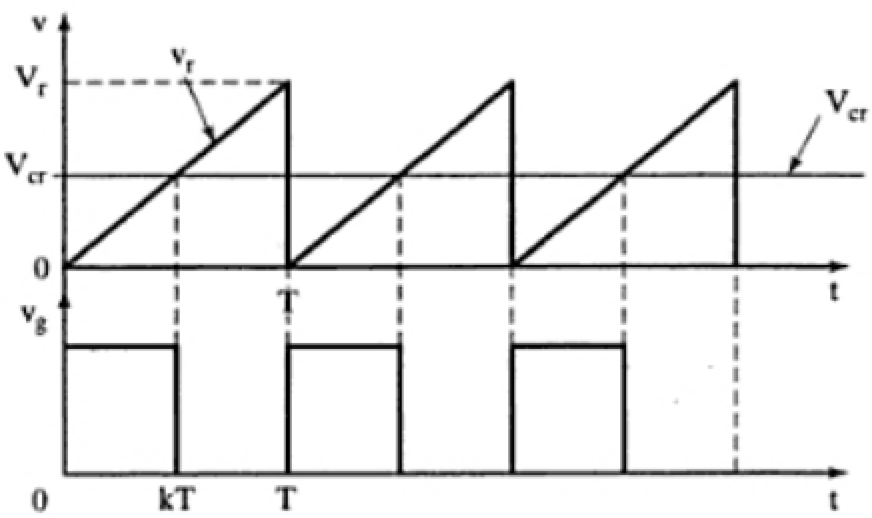
which must equal to the carrier signal $v_{cr} = V_{cr} = kT$. That is,

$$V_{cr} = \frac{V_r}{T}kT$$

which gives the duty cycle duty k as

$$k = \frac{V_{cr}}{V_r} = M$$

where M is called the *modulation index*. By varying the carrier signal v_{cr} from 0 to V_{cr}, the duty cycle k can be varied from 0 to 1.



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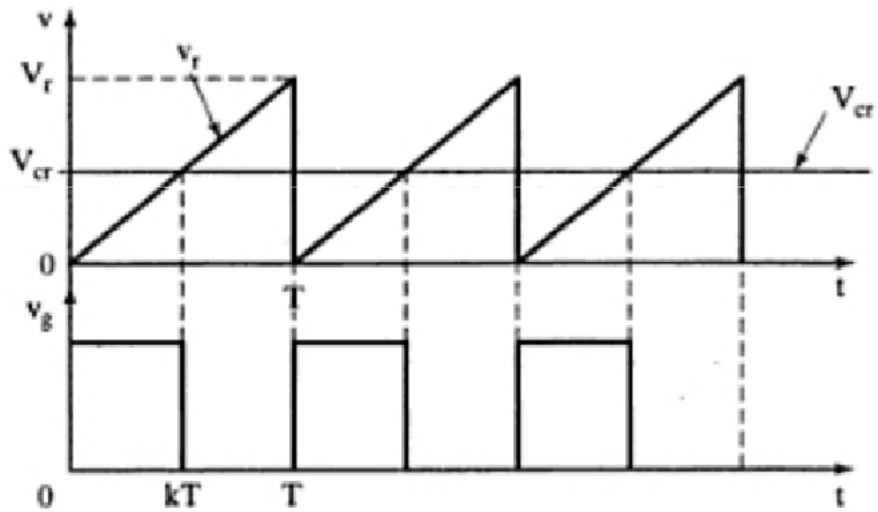
The algorithm to generate the gating signal is as follows:

1. Generate a triangular waveform of period T as the reference signal v_r and a dc carrier signal v_{cr}.
2. Compare these signals by a comparator to generate the difference $v_r - v_{cr}$ and then a hard limiter to obtain a square-wave gate pulse of width kT, which must be applied to the switching device through an isolating circuit.
3. Any variation in v_{cr} varies linearly with the duty cycle k.



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