Chopper fed DC drives

- A chopper is a static device that converts fixed DC input voltage to a variable dc output voltage directly
- A chopper is a high speed on/off semiconductor switch which connects source to load and disconnects the load from source at a fast speed.
- Choppers are used to get variable dc voltage from a dc source of fixed voltage. Self commutated devices such as MOSFET's, Power transistors, IGBT's, GTO's and IGCT's are used for building choppers because they can be commutated by a low power control signal and do not need communication circuit and can be operated at a higher frequency for the same rating.

Chopper circuits are used to control both separately excited and Series circuits.

Advantages of Chopper Circuits

Chopper circuits have several advantages over phase controlled converters

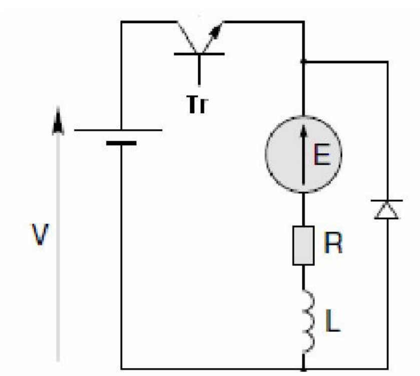
1. Ripple content in the output is small. Peak/average and rms/average current ratios are small. This improves the commutation and decreases the harmonic heating of the motor.
2. The chopper is supplied from a constant dc voltage using batteries. The problem of power factor does not occur at all. The conventional phase control method suffers from a poor power factor as the angle is delayed.
3. Current drawn by the chopper is smaller than in phase controlled converters.
4. Chopper circuit is simple and can be modified to provide regeneration and the control is also simple.

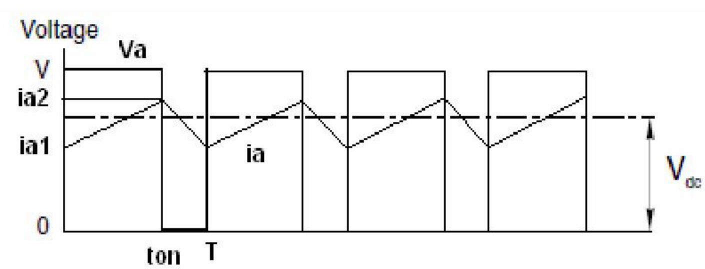
Chopper Controlled Separately Excited DC motor

If the source of supply is D.C. (for example in a battery vehicle or a rapid transit system) a chopper-type converter is usually employed. The chopper-fed motor is, if anything, rather better than the phase-controlled, because the armature current ripple can be less if a high chopping frequency is used.

Motoring Mode of Operation

A transistor is used to chop the DC input voltage in to pieces and chopped DC voltage is given to the motor as shown in the figure 2.17. Current limit control is used in chopper. In current limit control, the load current is allowed to vary between two given limits (i.e. Upper and lower limits). The ON and OFF times of the transistor is adjusted automatically, when the current increases beyond the upper limit the chopper is turned off, the load current free wheels and starts to decrease. When the current falls below the lower limit the chopper is turned ON. The current starts increasing if the load. The load current and voltage waveforms are shown in the figure 2.18. By assuming proper limits of current, the amplitude of ripple can be controlled.





The lower the current ripple, the higher the chopper frequency. By this switching losses increase. Discontinuous conduction avoid in this case. The current limit control is superior one.

Duty Interval

During the ON period of the chopper (i.e) duty interval $0 < t < t_{ON}$, motor terminal voltage V_a is a source voltage V and armature current increases from i_{a1} to i_{a2}. The operation is describe by,

$$R_a I_a + L_a \frac{di_a}{dt} + E = V \quad 0 \le t \le t_{ON} \quad (2.54)$$

In this interval the armature current increases from I_{a1} to I_{a2} since the motor is connected to the source during this interval, it is called as duty cycle.

Free Wheeling Interval

Chopper T_r is turned off at $t=t_{ON}$. Motor current free wheels through the diode D and the motor terminal voltage is zero. During interval $t_{ON} \le t \le T$. Motor operation during this interval is known as free wheeling interval and is described by

$$R_a I_a + L_a \frac{di_a}{dt} + E = 0 \quad t_{ON} \le t \le T \tag{2.55}$$

During this interval current decreases from i_{a2} to i_{a1}

Duty cycle (or) Duty Ratio:

Duty cycle is defined as the ratio of duty interval t_{ON} to chopper period T is called Duty cycle (or) Duty Ratio.

$$\delta = \frac{\text{Duty Interval}}{\text{Chopper Period}} = \frac{t_{ON}}{T} \tag{2.56}$$

From fig.

$$V_a = \frac{1}{T}\int_0^{t_{ON}} V dt \tag{2.57}$$

Solving the above,

$$V_a = \frac{V}{T}\int_0^{t_{ON}} dt = \frac{V}{T}[t]_0^{t_{ON}} = V\frac{t_{ON}}{T} \tag{2.58}$$

$$V_a = \delta V \tag{2.59}$$

Then the speed of the chopper drive can be obtained as

$$V_a = E + I_a R_a$$

Substituting V_a from equation (2.59) in the above equation we get,

$$\delta V = E + I_a R_a \tag{2.60}$$

Substituting $E = K\omega_m$ we get

$$I_a = \frac{\delta V - K\omega_m}{R_a} \quad (2.61)$$

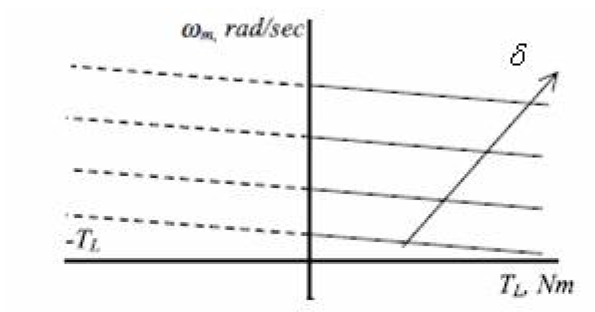
From above equation we get

$$\omega_m = \frac{\delta V}{K} - \frac{I_a R_a}{K} \quad (2.62)$$

Substituting $T = K\varphi I_a$ in above equation we get

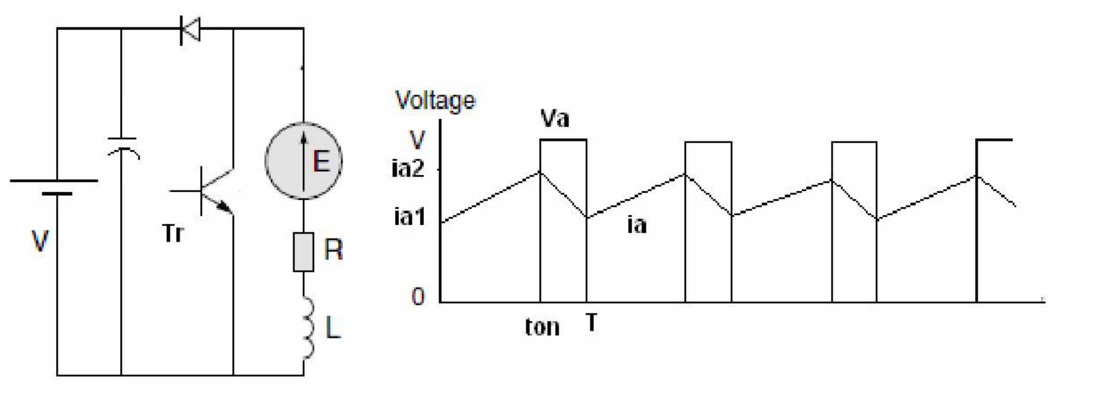
$$\omega_m = \frac{\delta V}{K} - \frac{R_a}{K^2\varphi} T \quad (2.63)$$

The torque speed characteristics of chopper fed separately excited DC motor is shown in the fig.



Regenerative Braking Mode

Regenerative braking operation by chopper is shown in the fig. Regenerative braking of a separately excited motor is fairly simple and can be carried out down to very low speeds.



In regenerative mode, the energy of the load is fed back to the supply system. The DC motor works as a generator during this mode. As long as the chopper is ON the mechanical energy is converted in to electrical energy by the motor, now working as a generator, increases the stored magnetic energy in the armature circuit. When chopper is switched off, a large voltage appears across the motor terminals this voltage is more than that of the supply voltage V and the energy stored in the inductance and energy supplied by the machine is fed back to the supply system. When the voltage of the motor fall to V, the diodes in the line blocks the current flow preventing any short circuit of the load can be supplied to the source. Very effective braking of motor is possible up to extreme small speeds.

Energy Storage Interval

The stored energy and energy supplied by the machine is fed to the source. The interval $0 < t < t_{ON}$ is now called energy storage interval and interval $t_{ON} \leq t \leq T$ is the duty interval.

Here duty ratio $$\delta = \frac{T - t_{ON}}{T} \tag{2.64}$$

From figure 2.21

$$V_a = \frac{1}{T}\int_{t_{ON}}^{T} V dt = \frac{V}{T}\int_{t_{ON}}^{T} dt = \frac{V}{T}\left[t\right]_{t_{ON}}^{T} = \frac{V}{T}\left(T - t_{ON}\right) \tag{2.65}$$

$$V_a = V\frac{T - t_{ON}}{T} = V\left(1 - \frac{t_{ON}}{T}\right) \tag{2.66}$$

Therefore the speed torque relations under braking operation is given as

$$\omega_m = \frac{(1-\delta)V}{K} - \frac{R_a}{K^2\varphi}T \tag{2.67}$$

Chopper control of DC series motor

Motoring control of series motor

The main drawback in the analysis of a chopper controlled series motor arises due to the non linear relationship between the induced voltage E and armature current Ia, because of the saturation in the magnetization characteristic. At a given motor speed ,the instantaneous back emf E changed between E_1 and E_2 as I_a changes between I_{a1} and I_{a2} as shown in figure.

Regenerative Braking of DC series Motor

With chopper control, regenerative braking of series motor can also be obtained. During regenerative braking, series motor functions as a self-excited series generator. For self excitation current flowing through the winding (field) should assist residual magnetism. Therefore when changing from motoring to braking connection, when armature current reverses field current should flow in the same direction. This is achieved by reversing the field with respect to armature when changing from motoring to braking operation.

The speed of this drive ω_m can be derived from the following equation

$E = V_a + I_a R_a$ but $V_a = \delta V$

$\therefore E = \delta V + I_a R_a \quad K_a \omega_m = \delta V + I_a R_a$

$$\omega_m = \frac{\delta V \pm I_a R_a}{K_a}$$

The speed – torque characteristics gives unstable operation with most loads shown in figure.Therefore regenerative braking of series motor is difficult.