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Notes for Class 2:

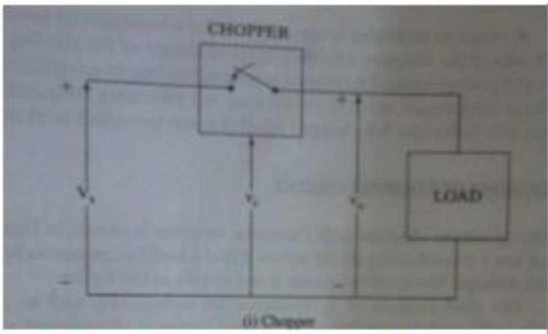
Topics of Discussion:

- The principle of Chopper
- 4 Quadrant Chopper Operation
- Pulsating Torques

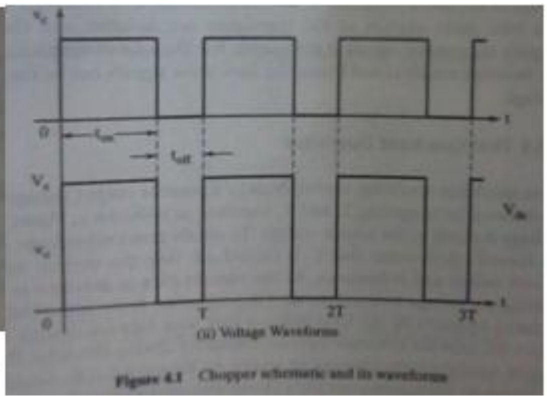
Chopper

Chopper control is generally used when we want to get variable DC voltage from a fixed DC voltage like a battery.

The philosophy of chopper is to chop the output voltage so as to get a variable voltage in average sense.



Courtesy: Electic Motor Drives-Modelling,Analysis and Conrol,P.Krishnan.



Considering the chopper as a switch whose switching frequency can be controlled so as to control the DC voltage .The average output voltage thus is given by:

$$Vdc = \frac{ton}{T} Vs$$

There are basically two parameters under our control to control the output DC voltage.The on time ton and the frequency of switching $\frac{1}{T}$. Controlling the output DC voltage using variable switching frequency is generally not used as the the design of input filter becomes difficult as well as predetermining switching losses.

4 Quadrant Chopper Operation:

The basic 4 quadrant chopper consists of 4 2-Quadrant bidirectional-current switches ,each switch consisting of a transistor and a diode .Considering the motor system as the load,the voltage and current across the load lead to 4 classification of quadrant of operation.The sequence of switching of switching so as to allow the load to operate in a given quadrant will be the focus over here along with the switching diagrams.The quadrants of the chopper are same as the quadrants for the DC motor.

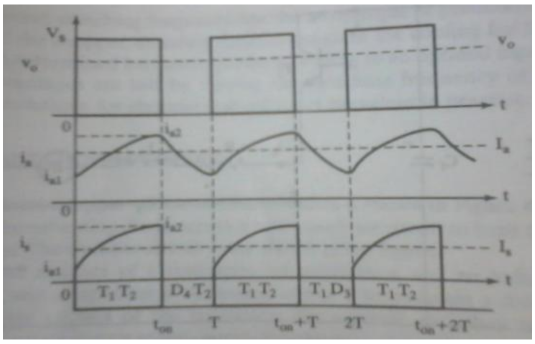
a. Quadrant 1:

For motor we know that in quadrant 1, the voltage and the current in the same sense leading to forward motoring. To maintain the motor in this mode,the voltage Vo and the current Io must too be of the same polarity in *average sense.*

The switching scheme followed is as follows:

S/R no.	Sequence	Effect
1	T1 and T2 on for ton	1.Voltage Vs appears across the motor 2.Current in the La increases
2	Switch off T1 (or T2)	1.Current in inductor tries to decrease,the voltage across it changes polarity thus causes D4 to get forward biased. 2.Since T2 is on ,and D4 is biased,the voltage across it becomes zero and the current decreases further until T1 is further switched on.
3	T1 and T2 on for ton	Same as step 1
4	Switch off T2(or T1)	Instead of D4-T2 ,D3-T1 perform similar function as in case of step 2.

Voltage and Current waveforms for Q-1 operation : (Courtesy Electric Motor Drives,Modelling Analysis and Control,P.Krishanan).



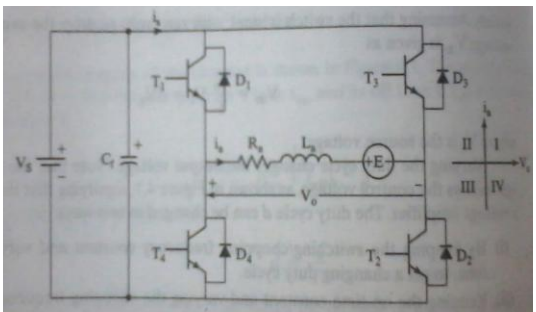


Figure 4.2 A four-quadrant chopper circuit

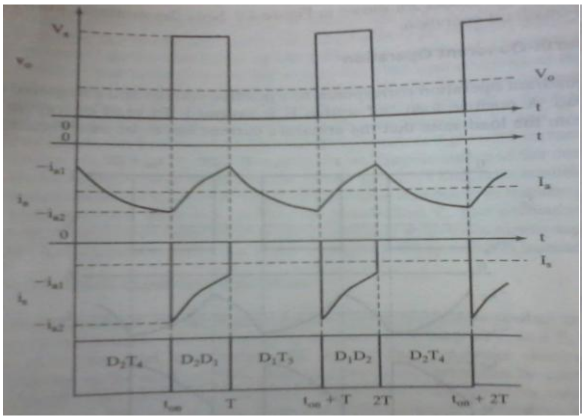
b. Quadrant 4:

For motor to operate in quadrant 4 i.e. Forward regeneration, the current flows from the load to the source. The emf of the motor should be in +ve sense but the current through it must reverse. The voltage across the load is positive in *average* sense and the current changes its direction. Consider the case when the motor is going from forward motoring to forward regeneration mode.

The switching scheme followed is as follows:

S/R no.	Sequence	Effect
1	Switch off T1 and T2	1.Since the motor is operating in forward motoring mode initially, switching T1 and T2 will cause D3 and D4 to get forward biased and cause the current in the armature to reduce to zero.
2	Switch on T4	1.The load is short circuited and the motor emf causes current to start flowing in negative direction via T4 and D2. 2.Thus charging of inductor takes place till it reaches desired peak.
3	Switch off T4	1.The current in the inductor can't change its direction and hence now causes D1 and D2 to get forward biased .It acts like a boost operation circuit with E in series with a charged inductor(with reverse voltage polaritynow as the current is decreasing) forcing current to flow from the load to source.
4	Switch on T4	Same as step 2. The process of step 2 and 3 continues until back emf becomes zero or rather all the inertial energy has been sucked out.

Voltage and Current waveforms for Q-1 operation : (Courtesy Electric Motor Drives,Modelling Analysis and Control,P.Krishnan).



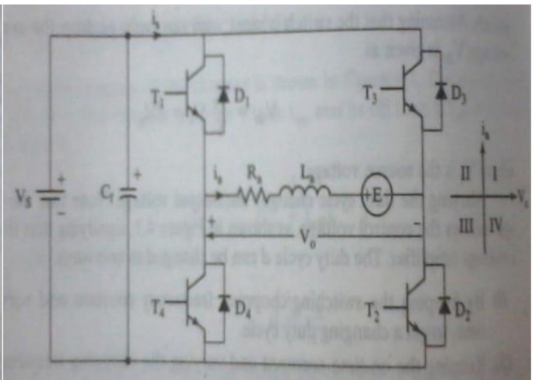


Figure 4.2 A four-quadrant chopper circuit

Point to note:

As compared to the general notion of regeneration in which the motor acts as a generator and supplies back to source provided it is at a smaller voltage,in this case regeneration can take place even if the back emf is less than the source voltage.The concept behind this is the boost operation provided by the inductor.Here inductor plays a very important role in the regeneration.The transfer of intertial energy of the motor back to the source can be viewed as a 2 step process.First the intertial energy is pumped into the inductor and then from the inductor to the source.

c. Quadrant -2 and Quadrant-3 :

The operation in quadrant 2 and 4 is similar to that of quadrant 1 and 3,and can be proceeded by first bringing the motor in quadrant-3 and then into quadrant-2.

Pulsating Torques:

The armature current as seen by various modes of operation shows that it has ac components.

On taking Fourier series of the output voltage and finding the contribution of harmonic components, it is observed that the average of the harmonic torques is zero and do not contribute to useful torque and power. But in high performance applications, it may cause vibrations and degradation of the process.

Also the various harmonic degrade the thermal capability of the motor by the additional loses produced by the harmonic currents.

The fundamental component of pulsating torque is given by :

$$ia1 = \frac{2Vs}{\pi\sqrt{R_a^2 + \omega_c^2 L_a^2}} \sin(\pi d)$$

As the above expression reflects , the effects of harmonic components can be reduced in the following two ways:

1. Increasing the chopper frequency ω_c
2. Increasing the Machine inductance.(Adding external inductance in the armature path)