Module-III

COMMUTAION CIRCUITS AND CHOPPER

COMMUTATION:

Turning off a conducting thyristor to enable it to revert to a non-conducting condition is known as commutation. In circuits where thyristors must be turned off after serving their purpose, this step is essential.

Commutation Types:

Commutation by Nature

Commutation by Force

I. Class A: Commutation by Self or Load

II. Class B: Commutation of Resonant Pulses

III. Complementary Commutation (Class C)

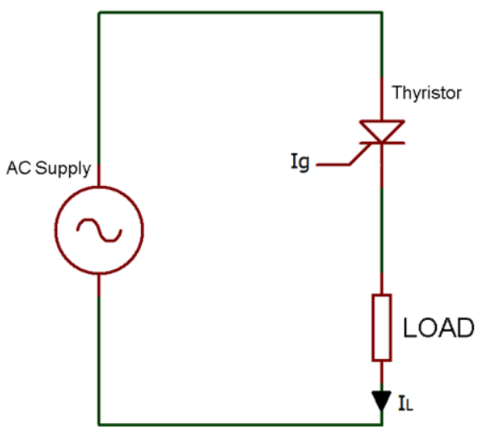
IV. Class D: Commutation by Impulse

V. Class E: Commutation from Outside

Natural Commutation:

Only AC circuits may experience natural commutation, which gets its name from the fact that no external circuit is needed. The thyristor turns off when a reverse voltage (negative cycle) is placed across it as soon as a positive cycle approach zero and the anode current is zero.

In phase-controlled rectifiers, cycloconverters, and AC voltage controllers, a natural commutation takes place.

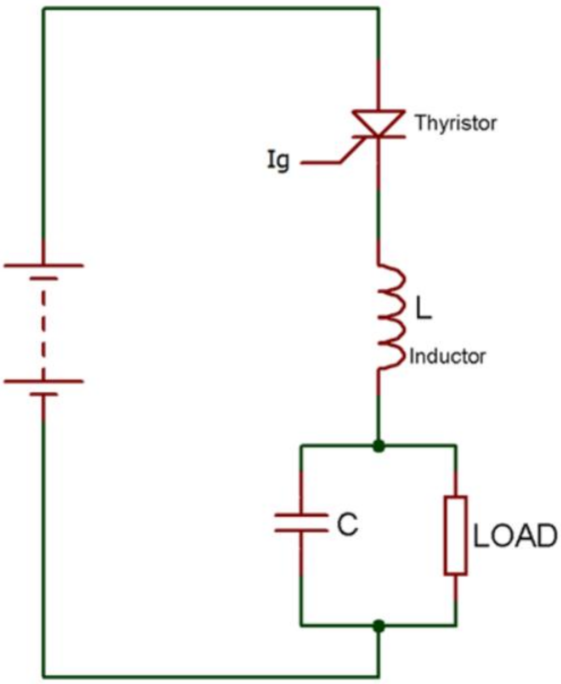


Forced Commutation:

As is well known, DC circuits do not naturally commutate, or have zero current. Therefore, forced commutation, also known as DC commutation, is used in DC circuits. It is known as forced commutation because it requires commutating components like capacitance and inductance to firmly lower the thyristor's anode current below the holding current value. Inverter and chopper circuits primarily employ forced commutation. The six categories into which forced commutation falls are described below:

Class A: Commutation by self or load:

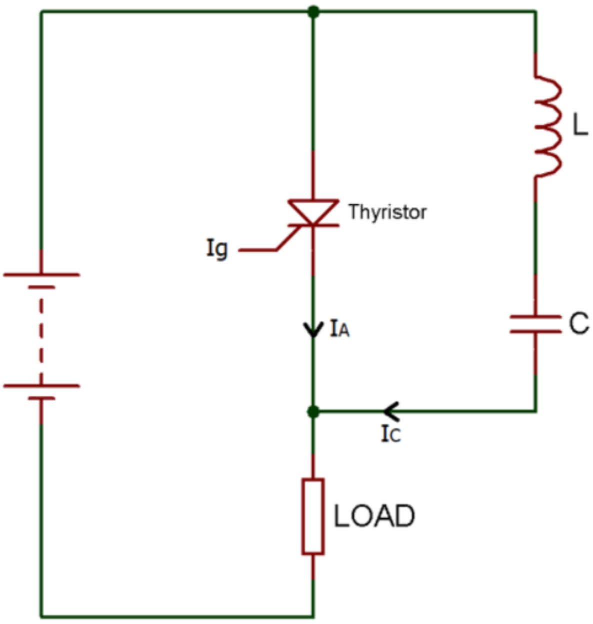
Among all thyristor commutation techniques, Class A, sometimes known as "Self-Commutation," is one of the most widely employed. The resistor, capacitor, and inductor in the circuit below comprise a second order damp circuit.



The thyristor needs a gate pulse to activate, therefore it won't switch on when we begin applying input voltage to the circuit. The current will now flow through the inductor and charge the capacitor to its maximum value or equal to the input voltage when the thyristor goes on or becomes forward biased. Now that the capacitor is completely charged, the inductor's polarity reverses and it begins to resist the current flow. The output current begins to drop as a result, eventually reaching zero. The thyristor goes off at this point because the current is less than its holding current.

Class B: Commutation of Resonant Pulses:

Another name for class B commutation is resonant-pulse commutation. The Class B and Class A circuits differ relatively slightly. Class A LC resonant circuits are linked in series, while Class B circuits are connected in parallel.

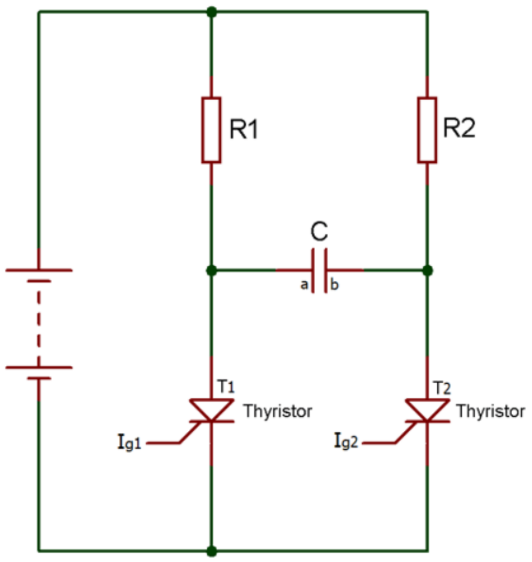


The capacitor now begins charging up to the input voltage (Vs) as the input voltage is provided, and the thyristor stays reverse biased until the gate pulse is delivered. The thyristor switches on when the gate pulse is applied, and current begins to flow in both directions. However, because of its high reactance, the continuous load current then passes through the resistance and inductance that are linked in series.

The reverse-polarity capacitor is then charged by a sinusoidal current passing through the LC resonant circuit. The current Ic (commutating current) therefore opposes the flow of the anode current IA due to the reverse voltage that develops across the thyristor. Because of this opposing commutating current, the thyristor switches off when the anode current drops below the holding current.

Complementary Commutation, Class C:

Complementary commutation is another name for class C commutation. Two thyristors are connected in parallel, one for the main and one for the auxiliary, as shown in the circuit below.

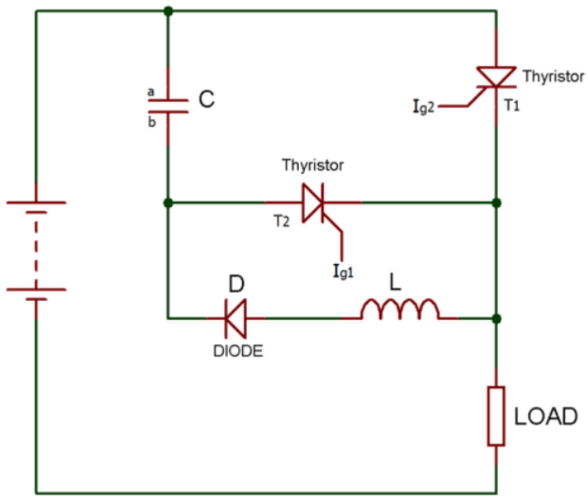


At first, the voltage across the capacitor is also 0, and the thyristor is in the OFF state. The current will now begin to flow from two routes when the gate pulse is applied to the main thyristor: R1-T1 and R2-C-T1. As a result, with plate B positive and plate A negative polarity, the capacitor also begins charging to a peak value equivalent to the input voltage.

The Thyristor T2 now comes ON when the gate pulse is delivered to it, and a negative polarity current appears across the Thyristor T1, turning T1 OFF. Additionally, the capacitor begins to charge with the opposite polarity. To put it simply, T1 turns T2 OFF when it turns ON, and T2 turns T1 OFF when it turns ON.

Class D: Commutation by Impulse:

Impulse commutation and voltage commutation are other names for class D commutation. The two thyristors T1 and T2, which are referred to as main and auxiliary, respectively, are likewise included in the Class D commutation circuit, just as in Class C. The commutation circuit in this case is made up of an auxiliary thyristor, an inductor, and a diode.



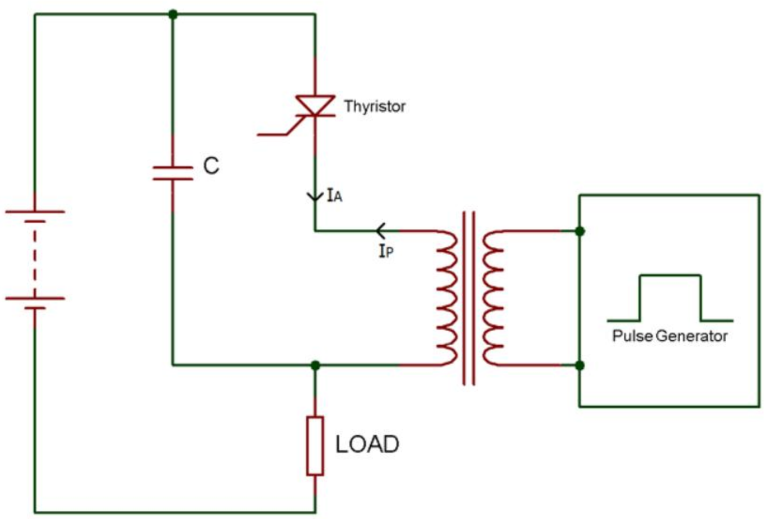
At first, the voltage across capacitor C is also zero, and both thyristors are in the OFF state. The load current now begins to flow through the Thyristor T1 as soon as the input voltage is applied and triggered. Additionally, the capacitor begins to charge with plate A's negative polarity and plate B's positive polarity.

The primary Thyristor T1 now shuts off as we activate the auxiliary Thyristor T2, and the capacitor begins charging with the opposite polarity. Its full charge leads the auxiliary Thyristor T2 to shut off because a capacitor prevents current from passing through it at that point.

Because both thyristors are now in the OFF state, the output current will also be 0.

Class E: Commutation of External Pulses:

Another name for class E commutation is external pulse commutation. The circuit schematic shows that the thyristor is now under forward bias. Thus, the current will show up at the load as soon as we activate the thyristor.



The pulse transformer is used to switch off the thyristor, and the capacitor in the circuit is used to protect it from dv/dt.

Now, an opposing current will flow in the cathode's direction when we send a pulse via the pulse transformer. If IA - IP < IH, the thyristor will switch off since this opposing current opposes the anode current's flow.

where IH stands for holding current, IP for pulse current, and IA for anode current.

CHOPPER:

One kind of electrical switching device that changes a fixed DC input voltage into a variable DC output value is a chopper circuit. Another name for chopper circuits is DC-to-DC converters.

CHOPPER TYPES:

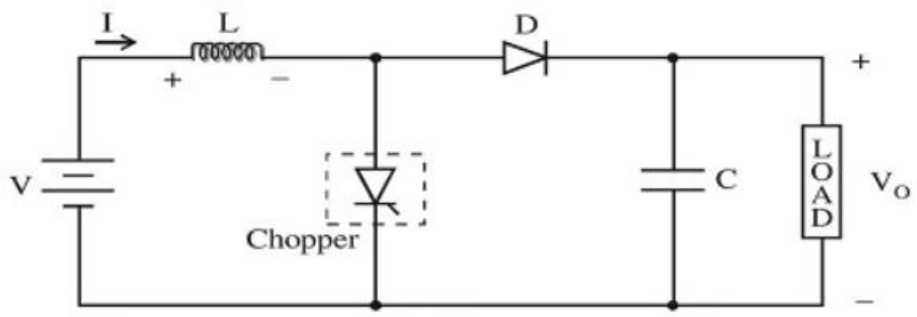
1. Boost converter or step-up chopper

2. Buck Converter or Step-Down Chopper

STEP UP CHOPPER:

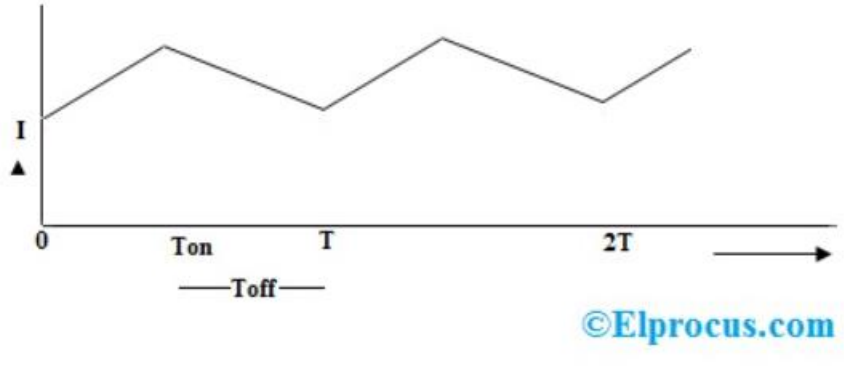
With DC current, a step-up chopper functions as a step-up transformer. When it is necessary to raise the output DC voltage above the input voltage, this chopper is used.

The figure above illustrates the basic operation of a step-up chopper. The supply voltage is linked in series with a sizable inducer L in the circuit. The output voltage to the load is continuously maintained by the capacitor. The diode stops current from moving from the source to the load.



The load receives supply voltage VS when the chopper is turned on, i.e. When V0 = VS, the inductor begins to store energy. The load current increases from Imin to Imax under certain circumstances.

The supply voltage travels from L to D to Load to VS when the chopper is turned off. In this time, the inductor discharges the stored e.m.f. to the load via diode D. As a result, the input voltage is less than the total voltage at the load, V0 = VS + Ldi/dt. Imax is been changed to Imin.



Step up Chopper Current Waveform

Where ΔI is the change in current, TON is is the duration, then

$L\frac{di}{dt} = V_{S},\ \frac{\Delta I}{T_{ON}} = \frac{V_S}{L}$

$\Delta I = \frac{V_S}{L} T_{ON}$ ------1

During T_{OFF} condition…

$\Delta I = \frac{V_0 - V_S}{L} T_{OFF}$ ----- 2

from 1 and 2 Average output voltage is given as $V_0 = \frac{V_S}{T - T_{ON}/T}$

Boost choppers are another name for step-up helicopters. Step-up choppers may be used as a voltage booster and to charge batteries.

STEPDOWN CHOPPER:

Another name for this is a buck converter. The average voltage output (VO) of this chopper is lower than the input voltage (VS); while the chopper is turned on, VO = VS, and when it is turned off, VO = 0.

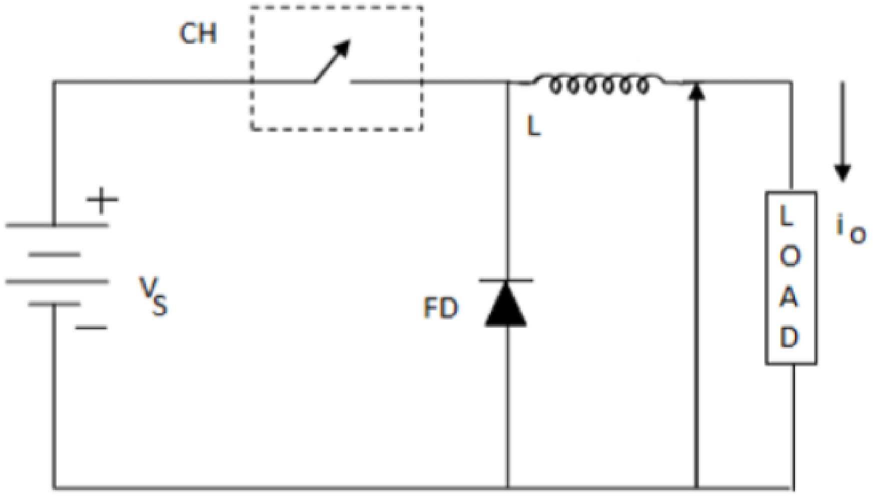
FD stands for free-wheel diode. Polarity reversal and discharge take place at the inductor when the chopper is turned off. The load receives the current via the inductor and the free-wheel diode. This provides,

Ldi/dt = V0

Inverted to LΔi/TOFF=V0

LΔi/TOFF = V0

Δi=V0TOFF/L



$$\frac{V_S - V_0}{L} T_{ON} = \frac{V_0}{L} T_{OFF}$$

$$\frac{V_S - V_0}{V_0} = \frac{T_{OFF}}{T_{ON}}$$

$$\frac{V_S}{V_0} = \frac{T_{ON} - T_{OFF}}{T_{ON}}$$

$$V_0 = \frac{T_{ON}}{T} V_S = DV_S$$

$$\Delta i = \frac{V_S - DV_S}{L} DT, \text{ from } D = \frac{T_{ON}}{T}$$

$$= \frac{V_S - (1-D)D}{Lf}$$

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

Waveforms of current and voltage:

The voltage output of a step-down chopper is always lower than the voltage input, as seen by the current and voltage waveforms below. The following waveform illustrates this.

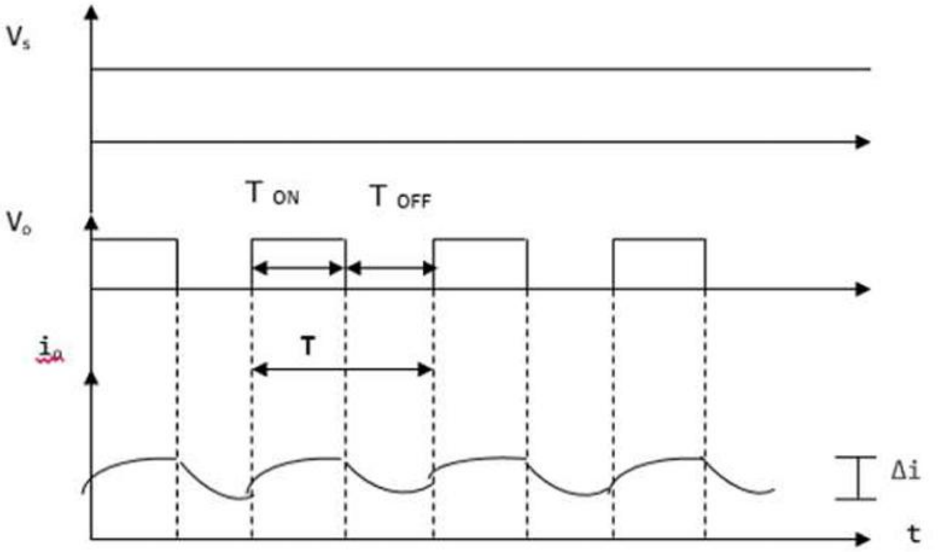


Figure: 3.6 Input and output waveforms

Five kinds of converters may be distinguished based on the direction of the output voltage and current:

1) Class A [Operation in One Quadrant]

2) Class B [Operation in One Quadrant]

3) Class C [Operation in Two Quadrants]

4) Class D Copter [Operation in Two Quadrants]

5) Class E Copter [Operation in Four Quadrants]

Class A:

Class A Chopper is a first quadrant chopper, with V0 = −VL V0 = • The supply voltage V is connected across the load when the chopper is turned on. • The load current flows through the FWD in the same direction when the chopper is off, and vO = 0. • The output voltage and current averages are consistently positive. A Class A Chopper is a first quadrant chopper. The load is linked across the supply voltage V when the chopper is turned on. • The load current flows through the FWD in the same direction when the chopper is off, and vO = 0. • The output voltage and current averages are consistently positive. A Class A Chopper is a step-down chopper that always transfers power from the source to the load. • It is used to regulate the dc motor's speed. • The Class A Chopper's performance may be examined using the output current equations that were derived in a step-down chopper with an R-L load.

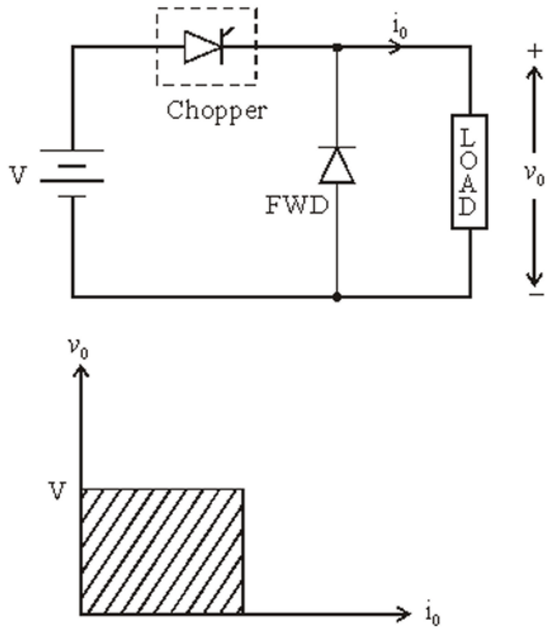


Figure: 3.10 circuit diagram and quadrant operation of Type A chopper

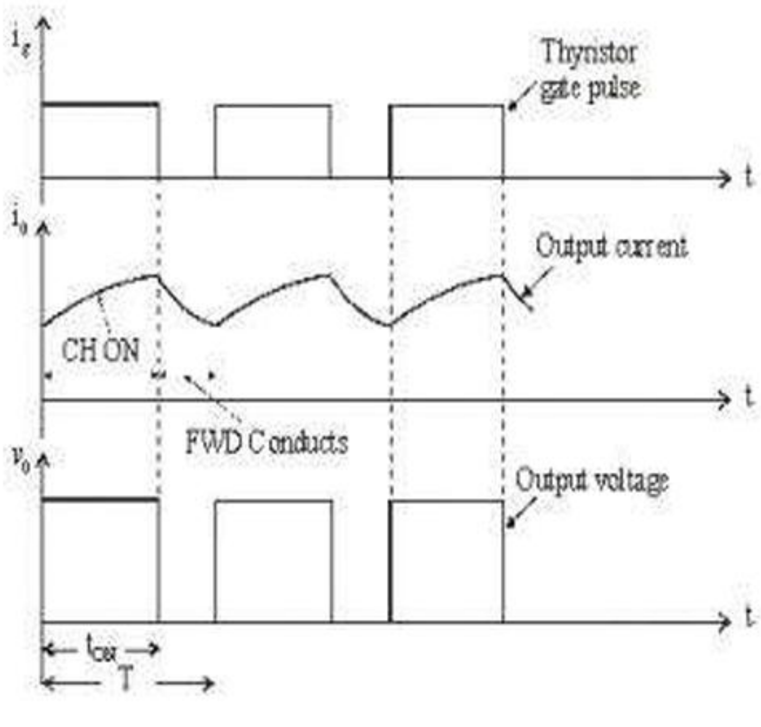


Figure: 3.11 Output voltage and current waveforms of type A chopper

CLASS B:

A step-up chopper is a class B chopper.

• E pushes a current through L and R in the opposite direction from the one seen in the picture when the chopper is turned on.

• The chopper's inductance L stores energy when it is turned on.

• Diode D conducts while Chopper is off, returning some of the energy stored in inductor L to the supply.

• The output voltage is positive on average. The average output current is negative.

Consequently, the second quadrant is where the Class B Chopper functions.

• Power moves from the load to the source in this chopper.

• Regenerative braking of a DC motor is accomplished using a Class B Chopper.

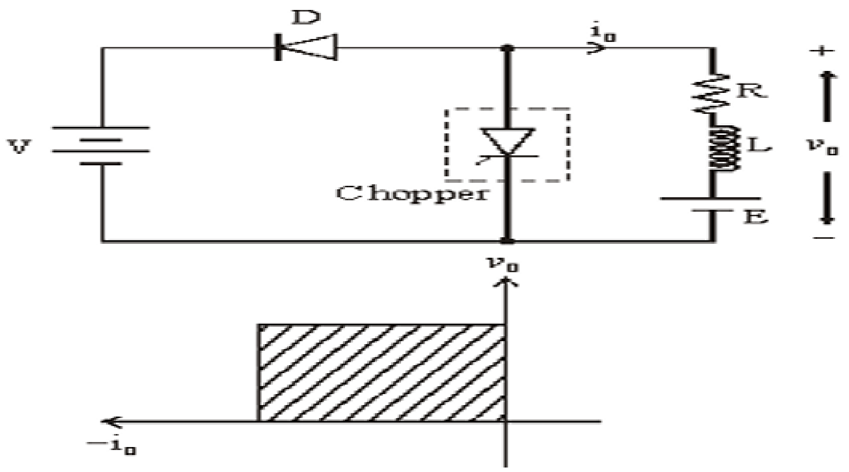


Figure: 3.12 circuit diagram and quadrant operation of Type B chopper

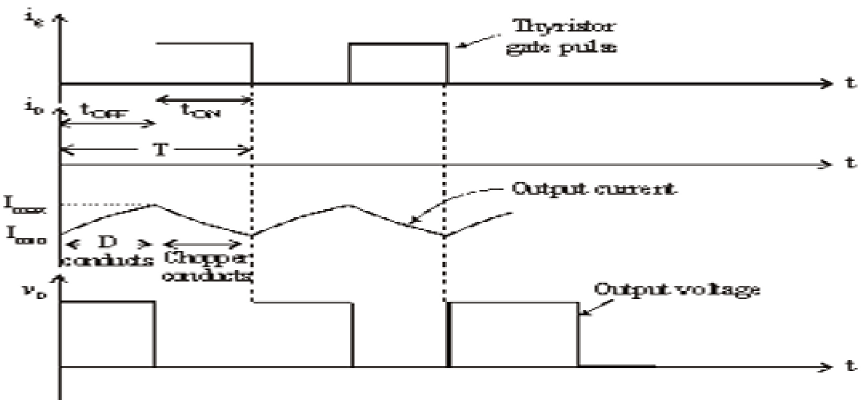


Figure: 3.13 Output voltage and current waveforms of type B chopper

Class C:

Step-up and step-down operations are both possible with the Class C Chopper.

• Class C helicopters are a cross between Class A and Class B helicopters.

• D2 conducts or CH1 is ON for operation in the first quadrant.

• D1 conducts or CH2 is ON for second quadrant operation.

• The load current is positive when CH1 is turned on.

• The load is powered by the source, and the output voltage is equal to "V."

• The output voltage is zero when CH1 is switched off because the energy stored in inductance L drives current through the diode D2.

• The current is still flowing in a good direction.

• The voltage E causes current to flow through L and CH2 in the opposite direction when CH2 is activated.

• There is no output voltage.

• When CH2 is turned off, current flows between diode D1 and the supply due to the energy stored in the inductance.

• When the output voltage is V, power moves from the load to the source and the input current becomes negative.

• The output voltage is positive on average.

• Both positive and negative values are possible for the average output current.

• It is not advisable to switch on choppers CH1 and CH2 at the same time as this might short circuit the supply.

• Class C Choppers may be employed for both regenerative braking and DC motor control.

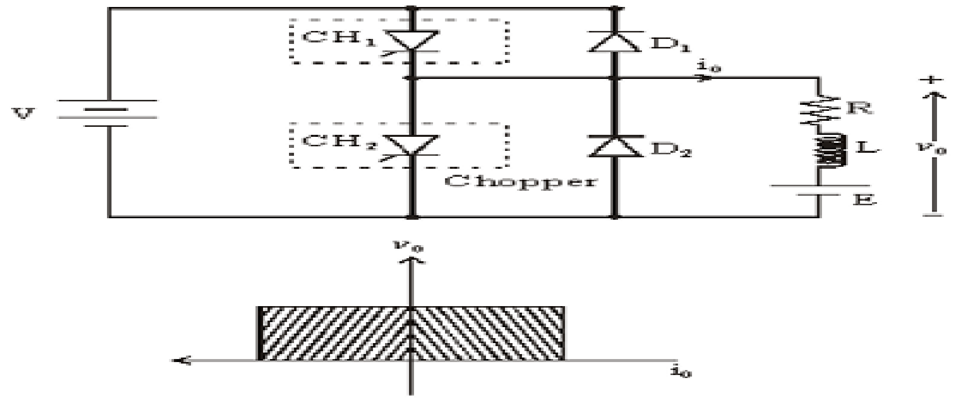


Figure: 3.14 circuit diagram and quadrant operation of Type C chopper

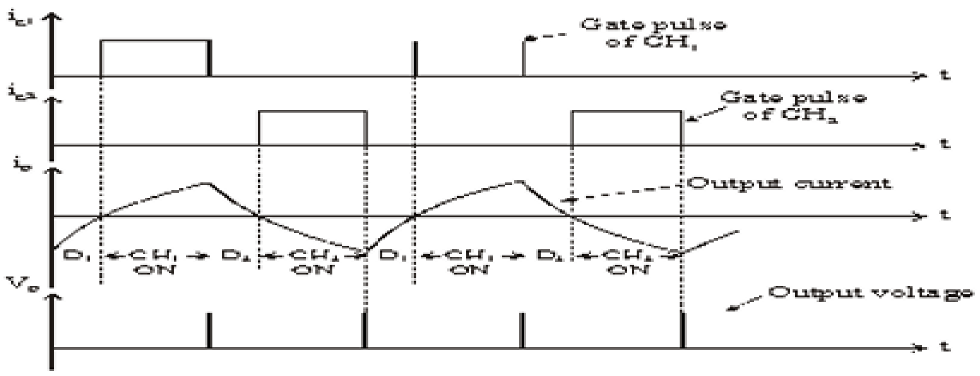


Figure: 3.15 Output voltage and current waveforms of type C chopper

CLASS D:

Class D helicopters operate in two quadrants.

• The output current flows through the load and the output voltage vO = V when both CH1 and CH2 are activated at the same time.

• Because of the energy stored in the inductor L, the load current flows through loads D1 and D2 in the same direction even when CH1 and CH2 are switched off.

• vO = -V is the output voltage.

• If the chopper's ON time exceeds its OFF duration, the average load voltage is positive.

• If tON < tOFF, the average output voltage becomes negative.

• As a result, load voltage may be either positive or negative, but load current is always positive.

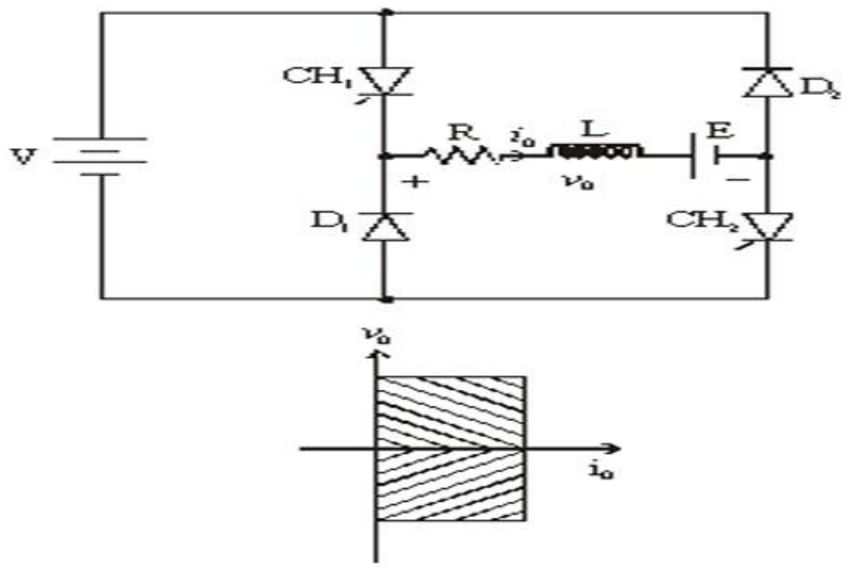


Figure: 3.16 circuit diagram and quadrant operation of Type D chopper

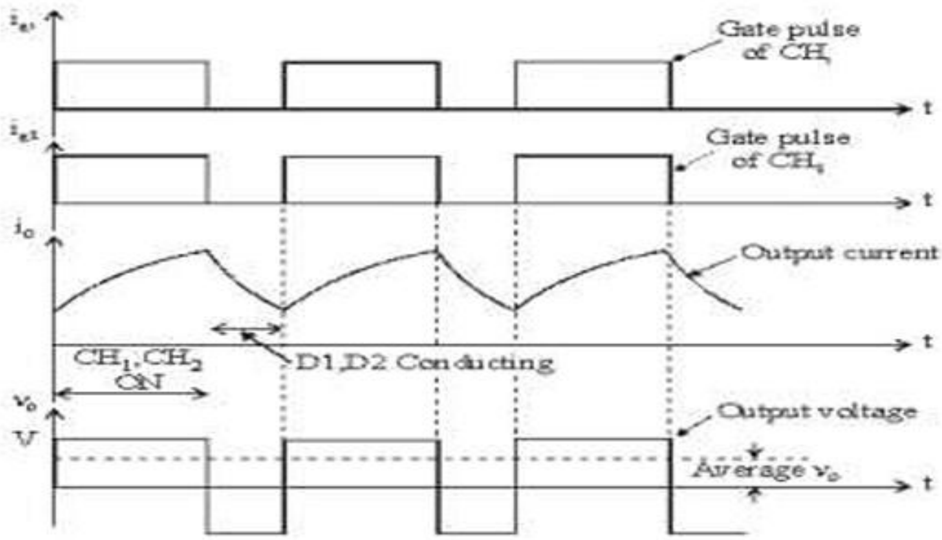


Figure: 3.17 Output voltage and current waveforms of type D chopper

CLASS E:

• Class E helicopters operate in four quadrants.

• When CH1 and CH4 are activated, output voltage vO = V and output current iO flows through CH1 and CH4 in a positive direction.

• This provides the operation for the first quadrant.

• The energy stored in the inductor L pushes iO through D2 and D3 in the same direction when both CH1 and CH4 are off, but the output voltage, vO, is equal to -V.

As a result, the fourth quadrant is where the helicopter functions.

• The output voltage vO = -V and the load current iO flow in the opposite direction when CH2 and CH3 are activated.

• The chopper functions in the third quadrant because both iO and vO are negative.

• The output voltage vO = V and the load current iO continue to flow in the same direction as D1 and D4 when both CH2 and CH3 are off.

Consequently, since iO is negative and vO is positive, the chopper works in the second quadrant.

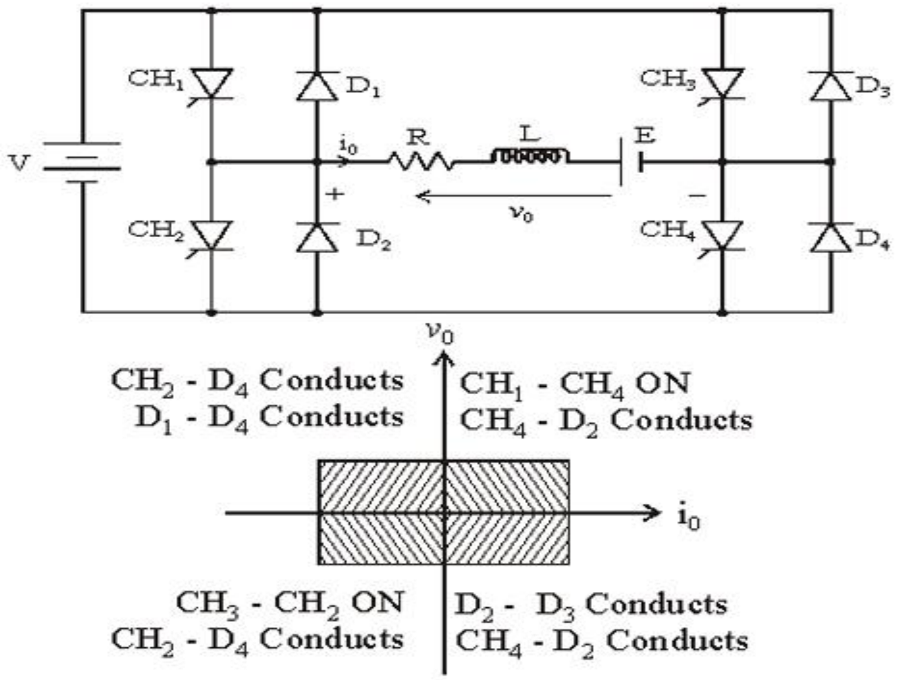


Figure: 3.18 circuit diagram and quadrant operation of Type E chopper

Chopper control strategies:

1. Control of Time Ratio

2. Limit Control of Current

We will examine two methods of altering the duty cycle in this article. The ratio of "on time" to "time period of a pulse" is known as the duty cycle.

Time Ratio Control: As the name implies, this method involves adjusting the time ratio, or the duty cycle ratio Ton/T. There are two methods for achieving this kind of control:

Frequency modulation control (FMC) and pulse width modulation (PWM)

PWM, or pulse width modulation

This method varies the "On Time" or "OFF Time" while maintaining a consistent time period. This allows you to adjust the duty cycle ratio. This technique is often referred to as pulse width modulation since it modifies the ON time or "pulse width."

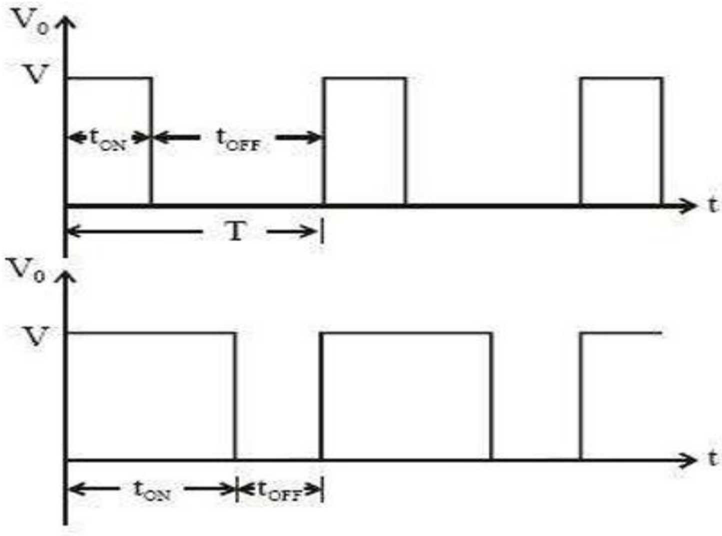


Figure: 3.2 pulse width modulation waveforms

Control of Frequency Modulation (FMC)

This control approach varies the "Time Period" while maintaining a constant "On Time" or "OFF Time." This technique is referred to as frequency modulation control because it alters the frequency in tandem with the time period.

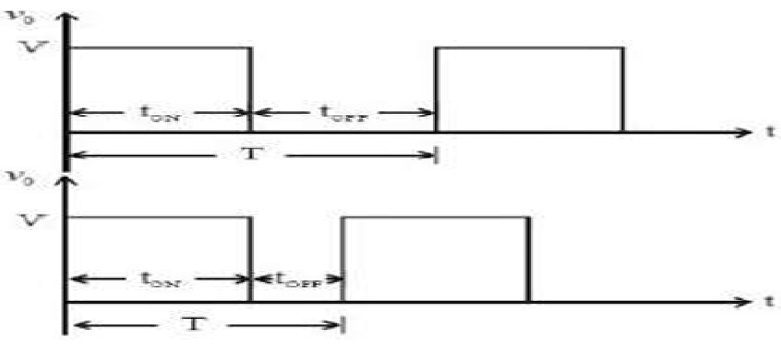


Figure: 3.3 Frequency modulation waveforms

Limit Control of Current:

As the name suggests, this control approach applies a certain limit on the present variation.

Only two values—the maximum current (I max) and the lowest current (I min)—can vary or alter while using this approach. The chopper is turned on when the current is at its lowest level. Following this, the current begins to increase. When it reaches its maximum value, the chopper is turned off, enabling the current to return to its lowest amount. This loop keeps going on and on.

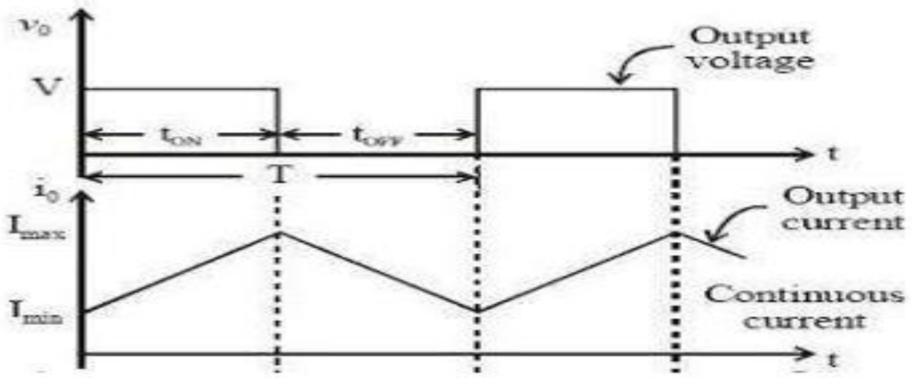
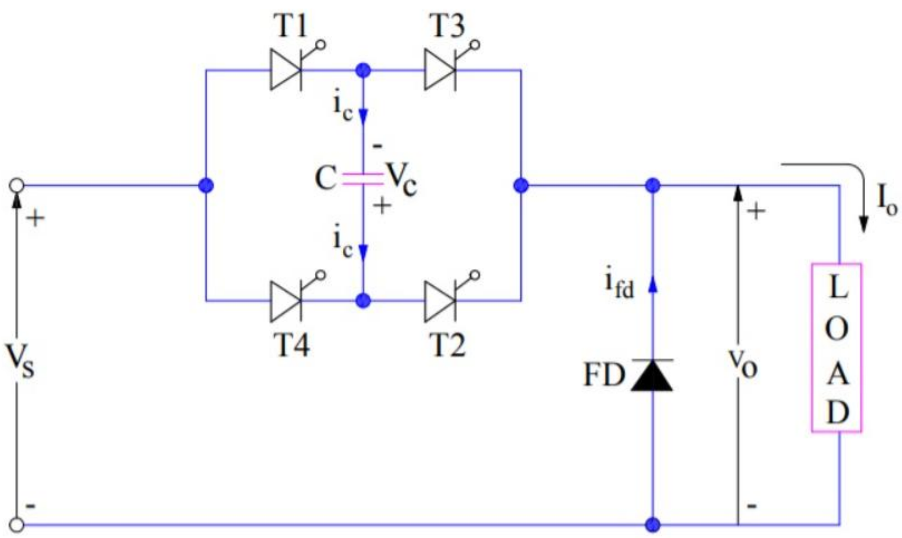


Figure: 3.4 current limit control waveforms

Commutated Load Chopper:

A load-commutated chopper is a particular kind of chopper that has one commutating capacitor and four thyristors. The circuit diagram of a load-commutated chopper is shown in the figure below. The commutating capacitor is denoted by C, while four thyristors are represented by T1–T4.



In order to conduct the load current alternately, thyristors T1 and T2 work as a single pair, while thyristors T3 and T4 work as a second pair. T1 and T2 function as primary thyristors while they are conducting, whilst T3, T4, and C function as commutating components. Likewise, T1, T2, and C function as commutating components when T3 and T4 are the primary thyristors. When necessary, the load current is carried by a free-wheeling diode (FD) linked across the load.

According to the circuit schematic, the capacitor C is first charged to a voltage Vs with the top plate being negative and the bottom plate being positive. The following presumptions are made in order to simplify the analysis:

The load current is steady.

Diodes and SCRs make the best switches.

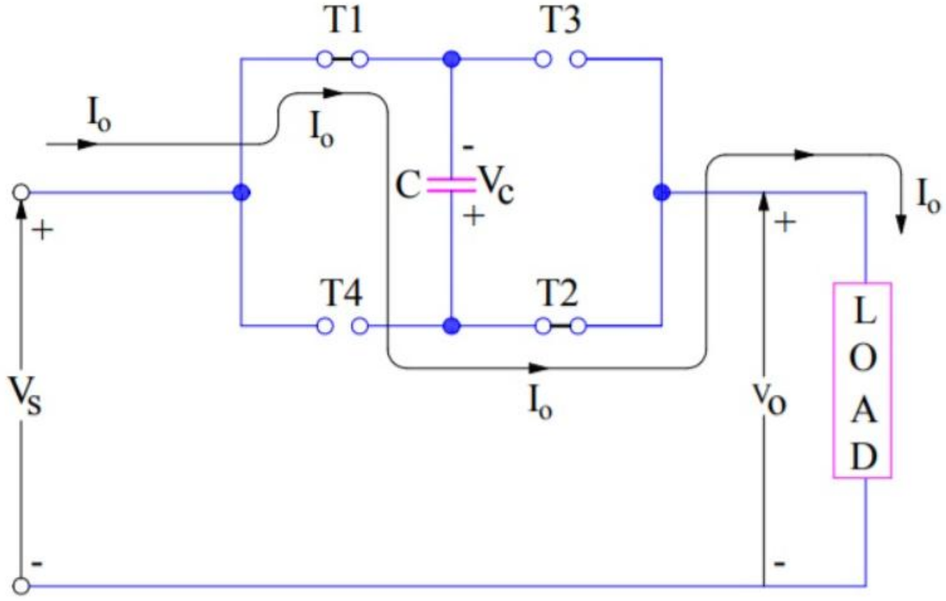
How a Load Commutated Chopper Operates:

Three distinct modes, which are detailed below, may be used to explain the load-commutated chopper's operation:

Mode I:

The load commutated chopper is prepared for operation after the capacitor C is charged with upper plate negative and bottom plate positive. The load current passes via T1, C, and T2 when thyristor pairs T1 and T2 are activated at t=0. The capacitor's top plate will begin charging from negative to positive as long as the load current is considered to be constant. The following is the output voltage Vo for this mode:

Vo = Vs + Vc



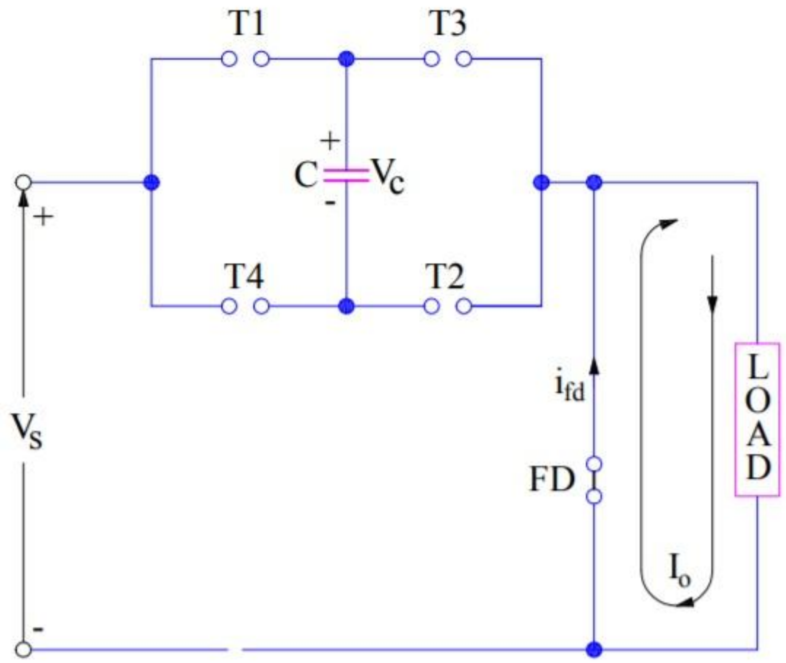
The output voltage will increase to 2Vs as soon as the thyristors T1 and T2 are activated since the capacitor voltage is -Vs at t=0. The graphic below depicts the load-commutated chopper operating in mode-I.

The charge of the capacitor C is linear, going from Vs at t=0 to (-Vs) at t=t1, as the load current is constant. The load voltage drops from 2Vs to zero at t = t1 when the capacitor voltage drops to -Vs, which basically indicates that the top plate is positive and the bottom plate is negative. To relate the items, please refer to the output voltage and time waveform.

It should be mentioned that the capacitor voltage causes T3 and T4 to be reverse biased when T1 and T2 are activated. Nevertheless, these thyristors become forward biased near the conclusion of Mode-I, or t=t1.

Mode II:

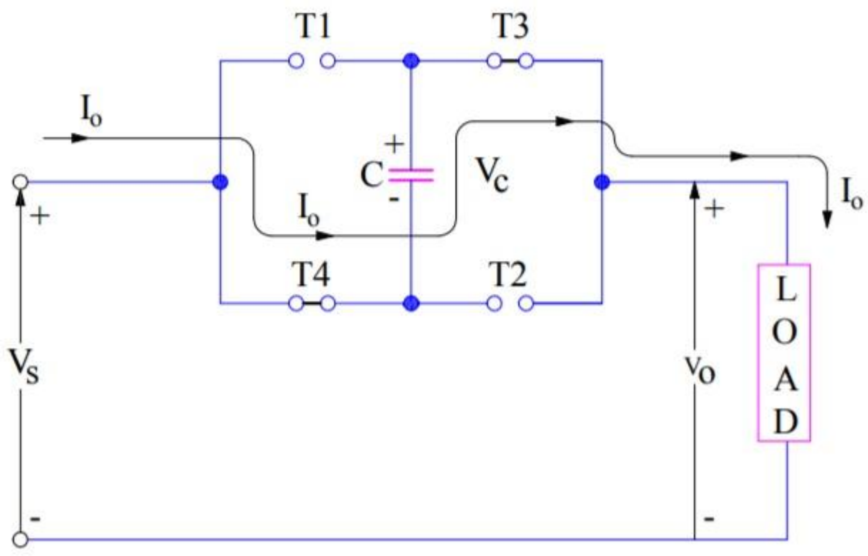
The capacitor C becomes significantly overcharged at t=t1, which causes the free-wheeling diode to become forward biased and transmit load current from T1 & T2 to FD. Load current free-wheels via FD starting at t=t1. The figure below illustrates this way of functioning.



Because the load current is flowing via the free-wheeling diode in this mode, the output voltage Vo is zero. At the conclusion of mode-I, or (-Vs), the voltage across the capacitor stays constant. Until the thyristors T3 and T4 are activated, this mode of operation keeps on. Assume that the Mode-II procedure lasts until t=t2. This indicates that Mode-III operation starts when thyristors T3 and T4 are activated at t=t2.

Mode-III:

Thyristor pairs T3 and T4 are activated at t=t2.Through capacitor C, T3, and T4, load current moves from source to load. The figure below illustrates this way of functioning.



Given that the load voltage is provided as

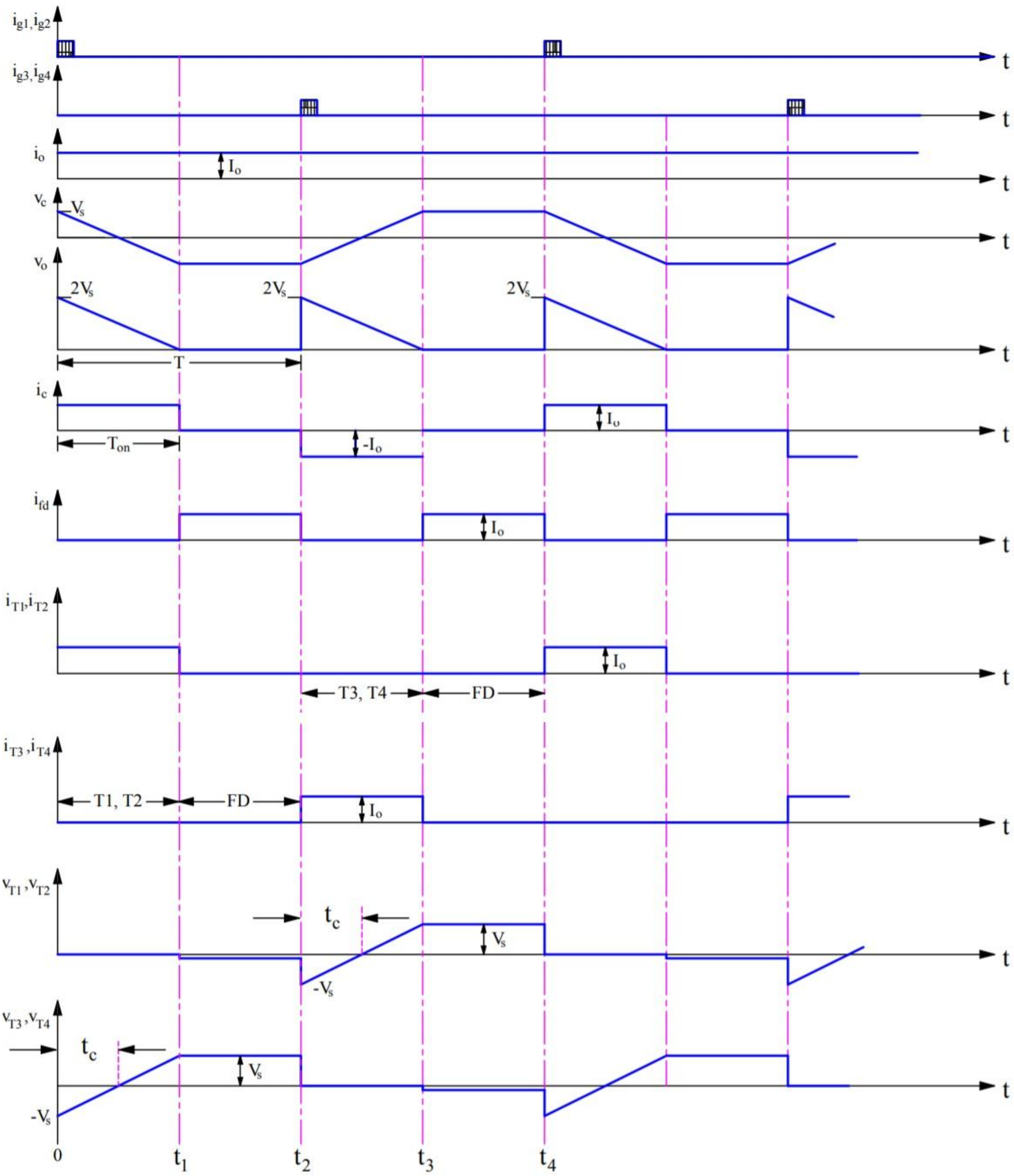
Vo = Vs + Vc

The load voltage equals 2Vs as soon as T3 and T4 are activated. Because of the reverse bias caused by the capacitor voltage, thyristor pairs T1 and T2 are switched off at t=t2. The capacitor will charge linearly from (-Vs) at t = t2 to Vs at t = t3 since the load current (Io) is passing through it. The load voltage drops from 2Vs to zero at t3 when the capacitor voltage equals Vs at t=t3. Keep in mind that thyristor pairs T1 & T2 become forward biased at t3 when the capacitor voltage reaches Vs, which indicates upper plate negative and lower plate positive.

Due to a little overcharge in capacitor C at t3, load current flows through the free-wheeling diode FD. Mode-I repeats when T1 and T2 are switched on at t4.

Similar Waveforms:

The graphic below displays a variety of waveforms associated with a load-commutated chopper.



Benefits and Drawbacks of a Load Commutated Chopper

Benefits:

The main benefits of a load-commutated helicopter are as follows:

Any quantity of load current may be commutated by it.

Commutation doesn't need an inducer. Inductors are often large, expensive, and intrusive.

Because load commutated choppers may operate at high frequencies in the range of kHz, they need very little filtering.

Drawbacks:

The main drawbacks of a load-commutated helicopter are as follows:

This chopper's peak voltage is double that of the source voltage. Filtering, however, may lower this peak.

Due to increased switching losses at high frequencies, this chopper's efficiency is limited for high power applications.

Double the supply voltage is applied to the free-wheeling diode.

The whole load current must be carried by the commutating capacitor at half the chopping frequency.