3.1 Introduction-DC-DC Converters-Chopper

There are two basic types of dc-dc converter circuits, termed asStep up and step down chopper.

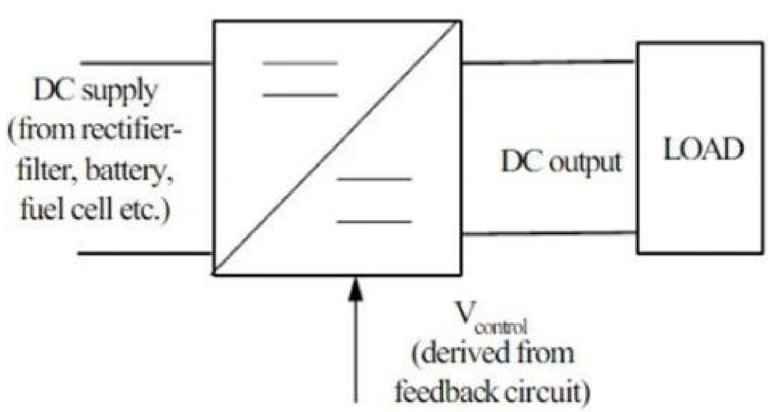
- In all of these circuits, a power device is used as a switch.
- In all these circuits, the thyristor is connected in series with load to a dc supply, or a positive (forward) voltage is applied between anode and cathode terminals. The thyristor turns off, when the current decreases below the holding current, or a reverse (negative) voltage is applied between anode and cathode terminals. So, a thyristor is to be force- commutated, for which additional circuit is to be used, where another thyristor is often used.
- Later, GTO's came into the market, which can also be turned off by a negative current fed at its gate, unlike thyristors, requiring proper control circuit. The turn on and turn-off times of GTOs are lower than those of thyristors. So, the frequency used in GTO based choppers can be increased, thus reducing the size of filters.
- Earlier, dc-dc converters were called 'choppers', where thyristors are used. It may be noted here that converter (dc-dc) is a 'step-up chopper'. With the advent of bipolar junction transistor (BJT), which is termed as self- commutated device, it is used as a switch, instead buck converter (dc-dc) is called as 'step-down chopper', whereas boost of thyristor, in dc- dc converters. This device (NPN transistor) is switched on by a positive current through the base and emitter, and then switched off by withdrawing the above signal. The collector is connected to a positive voltage.

❖ Now-a days, MOSFETs are used as a switching device in low voltage and high current applications. It may be noted that, as the turn-on and turn- off time of MOSFETs are lower as compared to other switching devices, the frequency used for the dc-dc converters using it (MOSFET) is high, thus, reducing the size of filters as stated earlier.

❖ These converters are now being used for applications, one of the most important being Switched Mode Power Supply (SMPS). Similarly, when application requires high voltage, Insulated Gate Bi-polar Transistors (IGBT) are preferred over BJTs, as the turn-on and turn-off times of IGBTs are lower than those of power transistors (BJT), thus the frequency can be increased in the converters using them. So, mostly self-commutated devices of transistor family as described are being increasingly used in dc- dc converters.

DEFINITION:

- Converting the unregulated DC input to a controlled DC output with adesired voltage level.



- **DC to DC converter** is very much needed nowadays as many industrial applications are dependent upon DC voltage source. The performance of these applications will be improved if we use a variable DC supply. It will help to improve controllability of the equipments also. Examples of such applications are subway cars, trolley buses, battery operated vehicles etc.

We can control and vary a constant DC voltage with the help of a chopper. Chopper is a basically static power electronics device which converts fixed DC voltage/power to variable DC voltage or power. It is nothing but a high speed switch which connects and disconnects the load from source at a high rate to get variable or chopped voltage at the output.

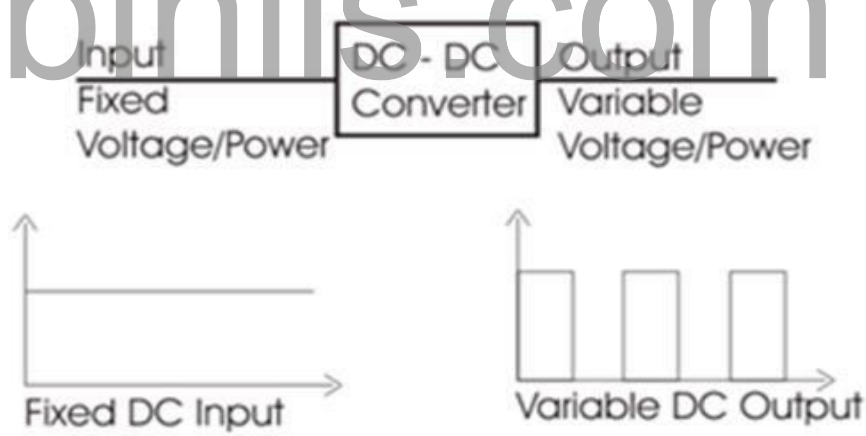


Figure 3.1.2 DC-DC Power conversion block diagram

[Source: "Power Electronics" *by* P.S.Bimbra, Khanna Publishers *Page: 249]*

Chopper can increase or decrease the DC voltage level at its opposite side. So, chopper serves the same purpose in DC circuit transformers in case of ac circuit. So it is also known as DC transformer.

DEVICES USED IN CHOPPER

Low power application: GTO, IGBT, Power BJT, Power MOSFET etc.High power application: Thyristor or SCR.

DC-DC converters types

- Vo<Vin - Buck converter
- Vo>Vin - Boost converter
- Vo<Vin or Vo>Vin - Buck-Boost converter,

APPLICATIONS OF CHOPPER

DC to DC converters are applied for many applications such as in Switched Mode Power Supply System.

DC motors as speed controllers.

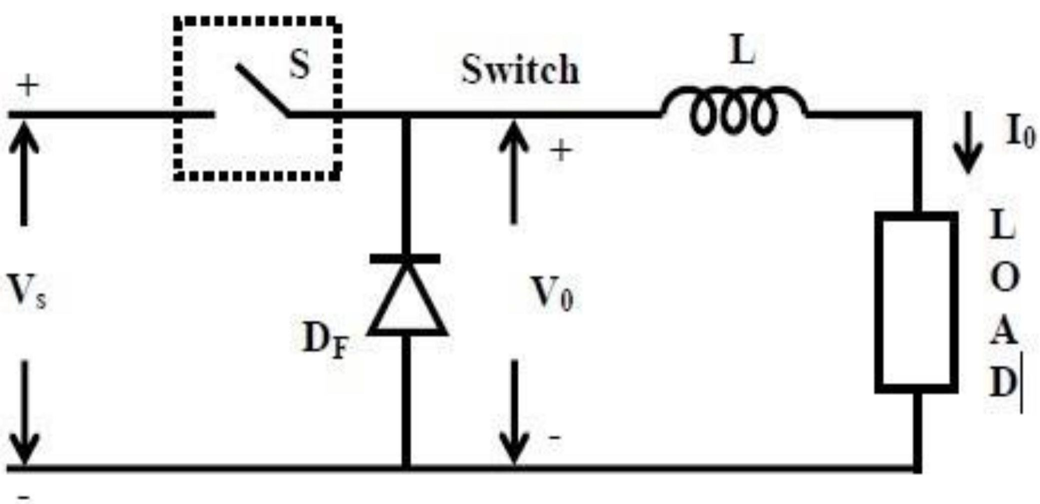
DC voltage boosters. Battery chargers.

Railway systems. Electric cars etc…

3.2 Step down & Step up chopper

A buck converter (Step down chopper) is shown in Fig. Only a switch is shown, for which a device as described earlier belonging to transistor family is used. Also a diode (termed as free wheeling) is used to allow the load current to flow through it, when the switch (i.e., a device) is turned off. The load is inductive (R-L) one. In some cases, a battery (or back emf) is connected in series with the load (inductive). Due to the load inductance, the load current must be allowed a path, which is provided by the diode; otherwise, i.e., in the absence of the above diode, the high induced emf of the inductance, as the load current tends to decrease, may cause damage to the switching device. If the switching device used is a thyristor, this circuit is called as a step-down chopper, as the output voltage is normally lower than the input voltage. Similarly, this dc-dc converter is termed as buck one, due to reason given later.

Figure 3.2.1 Step down chopper



Normally, due to turn-on delay of the device used, the duty ratio (k) is not zero, but has some positive value. Similarly, due to requirement of turn-off time of the device, the duty ratio (k) is less than 1.0. So, the range of duty ratio is reduced. It may be noted that the output voltage is lower than the input voltage. Also, the average output voltage increases, as the duty ratio is increased. So, a variable dc output voltage is obtained from a constant dc input voltage. The load current is assumed to be continuous as shown in Fig. b. The load current increases in the ON period, as the input voltage appears across the load, and it (load current) decreases in the OFF period, as it flows in the diode, but is positive at the end of the time period, T

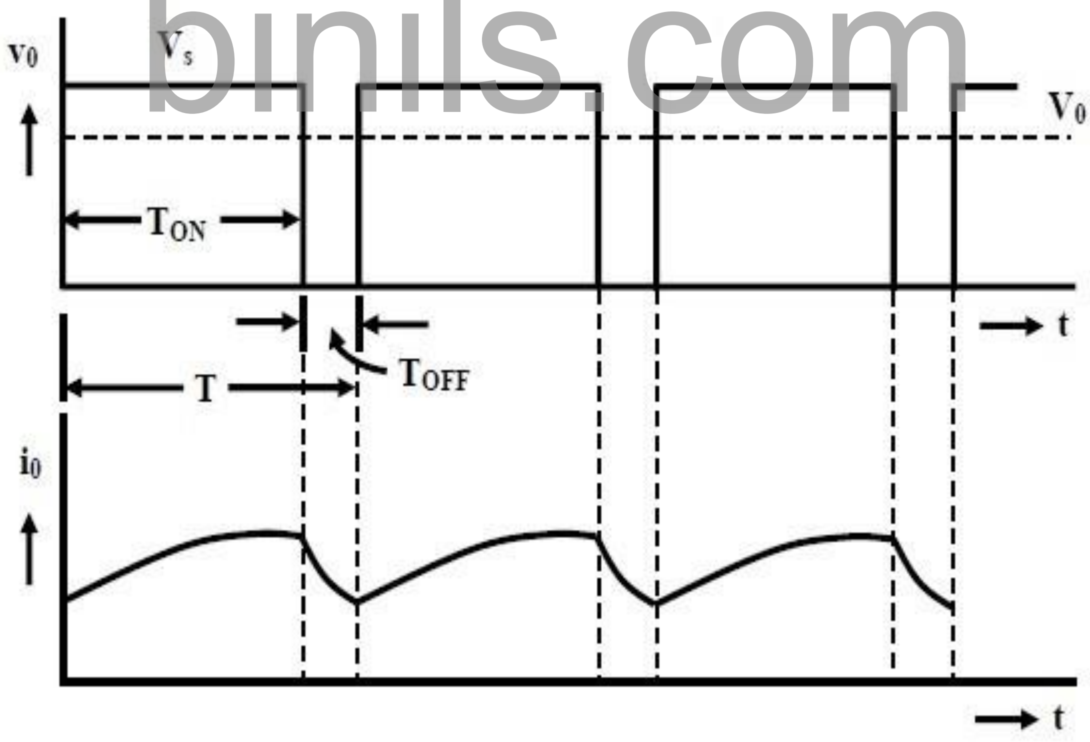


Figure 3.2.2 Step down chopper waveform

Step up chopper

A boost converter (Step up chopper) is shown in Fig. Only a switch is shown, for which a device belonging to transistor family is generally used. Also, a diode is used in series with the load. The load is of the same type as given earlier. The inductance of the load is small. An inductance, L is assumed in series with the input supply. The position of the switch and diode in this circuit may be noted, as compared to their position in the buck converter .

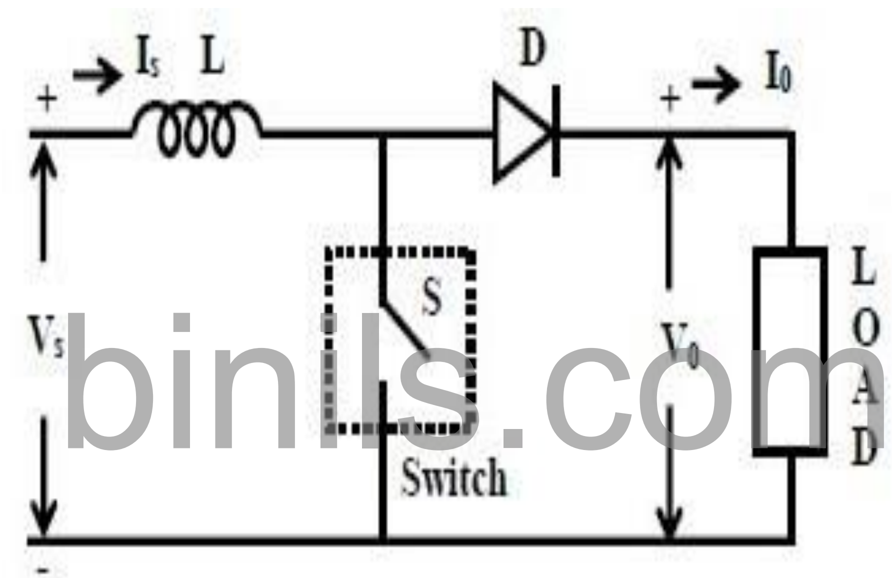


Figure 3.2.3 Step up chopper

[Source: “Power Electronics” by P.S.Bimbra, Khanna Publishers Page: 252]

In this case, the output voltage is higher than the input voltage, as contrasted with the previous case of buck converter (dc-dc). So, this is called boost converter (dc-dc), when a self- commutated device is used as a switch. Instead, if thyristor is used in its place, this is termed as step-up chopper. The variation (range) of the output voltage can be easily computed.

3.3 Control strategy of Chopper

There are mainly two techniques or methods to control the output voltage of a chopper ie Time Ratio Control Method and Current Limit Control. The output voltage of chopper depends on the duty cycle. By changing the duty cycle, the output voltage can be varied.

Time-ratio Control

In the time ratio control the value of the duty ratio, TTkON/= is varied. There are two ways, which are constant frequency operation, and variable frequency operation.

Constant Frequency Operation:

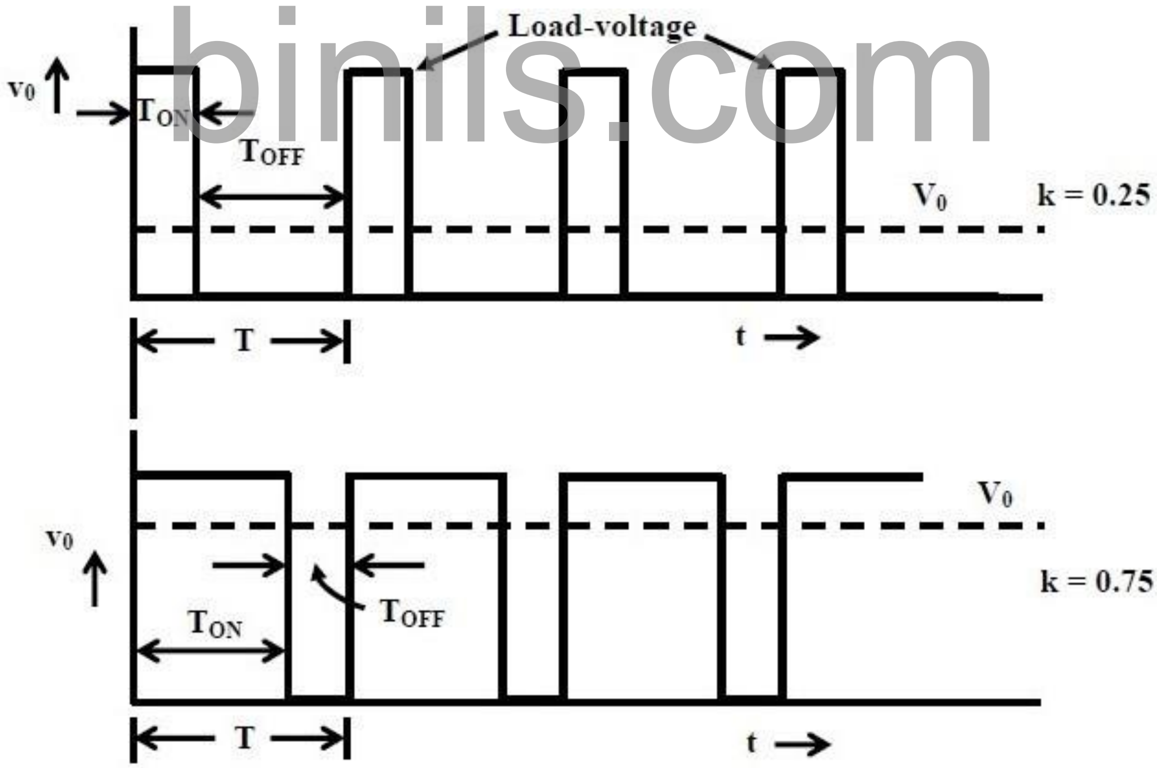


Figure 3.3.1 Constant Frequency System

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers Page: 250]

In this control strategy, the ON time, TON is varied, keeping the frequency , or time period (f=1/T) constant. This is also called as pulse width modulation control (PWM). Two cases with duty ratios, as (a) 0.25 (25%), and (b) 0.75 (75%) are shown in Fig. Hence, the output voltage can be varied by varying ON time, TON.

Variable Frequency Operation

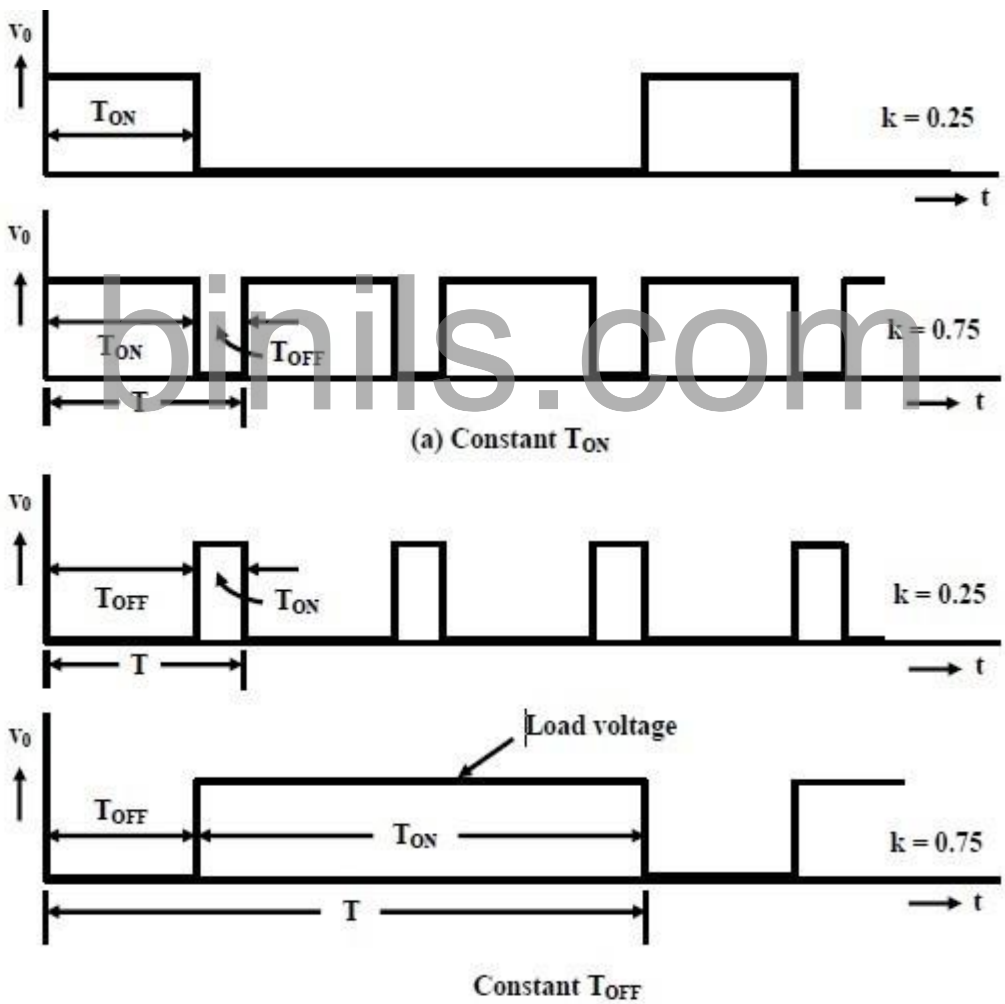


Figure 3.3.2 Variable Frequency System

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers Page: 250]

In this control strategy, the frequency (f=1/T), or time period T is varied, keeping either (a) the ON time, constant, or (b) the OFF time, constant. This is also called as frequency modulation control. Two cases with (a) the ON time, constant, and (b) the OFF time, constant, with variable frequency or time period are shown in Fig. The output voltage can be varied in both cases, with the change in duty ratio.

There are major disadvantages in this control strategy. These are:

(a) The 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.

(b) For the control of a duty ratio, frequency variation would be wide. As such, there is a possibly of interference with systems using certain frequencies, such as signaling and telephone line, in frequency modulation technique.

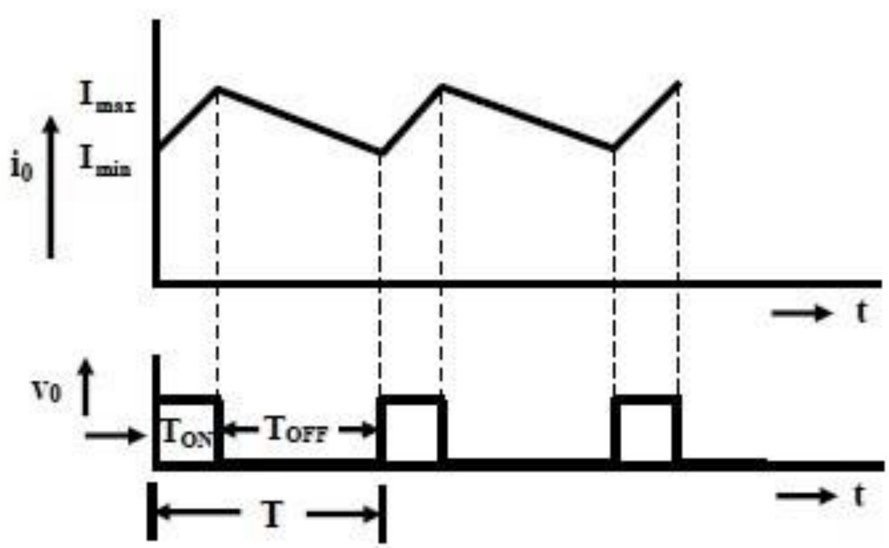
(c) The large OFF time in frequency modulation technique, may make the load current discontinuous, which is undesirable.

Thus, the constant frequency system using PWM is the preferredscheme for dc-dc converters.

Current Limit Control

As can be observed from the current waveforms for the types of dc-dc converters described earlier, the current changes between the maximum and minimum values, if it (current) is continuous. In the current limit control strategy, the switch in dc-dc converter (chopper) is turned ON and OFF, so that the current is maintained between two (upper and lower) limits. When the current exceed upper (maximum) limit, the switch is turned OFF. During OFF period, the current freewheels in say, buck converter (dc-dc) through the diode, , and decreases exponentially. When it reaches lower (minimum) limit, the switch is turned ON. This type of control is possible, either with constant frequency, or constant ON time, . This is used only, when the load has energy storage elements, i.e. inductance, L. The reference values are load current or load voltage. This is shown in Fig. In this case, the current is continuous, varying between and , which decides the frequency used for switching. The ripple in the load current can be reduced, if the difference between the upper and lower limits is reduced, thereby making it minimum. This in turn increases the frequency, thereby increasing the switching losses.

Figure 3.3.3 Current Limit Control



3.4 Types of choppers

The semiconductor devices are arranged appropriately in a chopperto work in any of the four quadrants.

we can classify chopper circuits according to their working in anyof these four quadrants as type A, type B, type C, type D and type E.

TYPE A CHOPPER OR FIRST QUADRANT CHOPPER

- This type of chopper is shown in the figure. It is known as first-quadrant chopper or type A chopper. When the chopper is on, $v_0 = V_S$ as a result and the current flows in the direction of the load. But when the chopper is off v_0 is zero but I_0 continues to flow in the same direction through the freewheeling diode FD, thus average value of voltage and current say V_0 and I_0 will be always positive as shown in the graph.

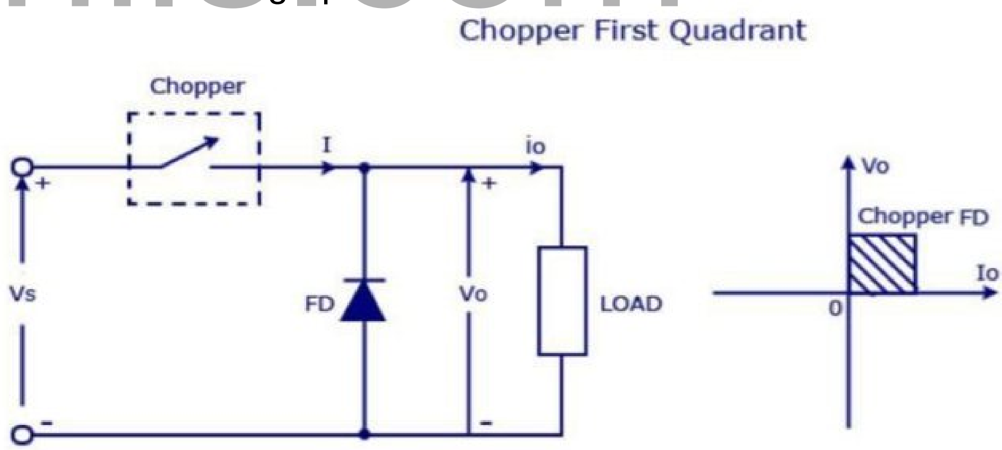


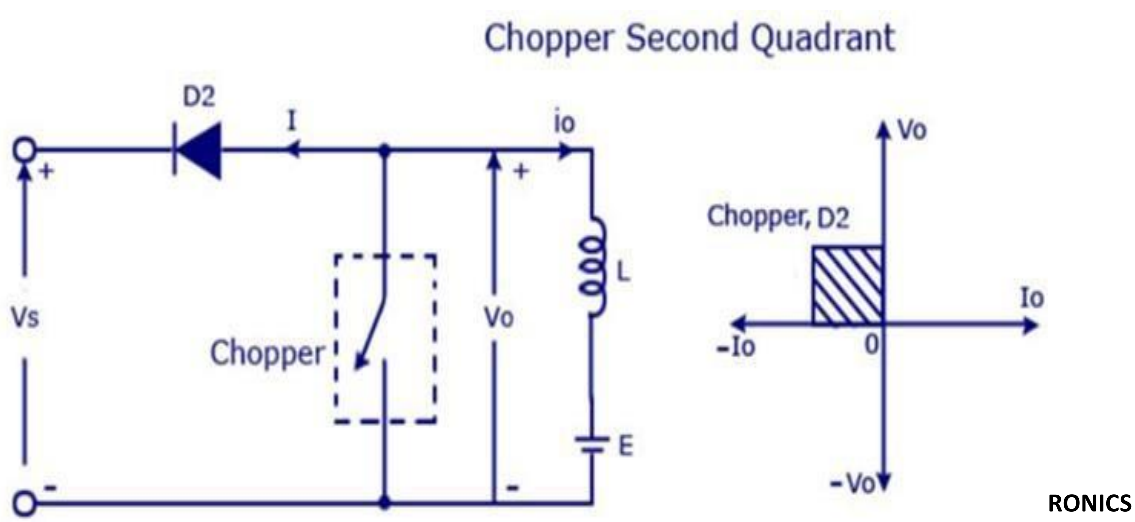
Figure 3.4.1 Type A Chopper or First–Quadrant Chopper

- In type A chopper the power flow will be always from source to theload. As the average voltage V_0 is less than the dc input voltage V_S.

TYPE B CHOPPER OR SECOND-QUADRANT CHOPPER

Type B Chopper Or Second-quadrant Chopper

In type B or second quadrant chopper the load must always contain a dc source E. When the chopper is on, v_0 is zero but the load voltage E drives the current through the inductor L and the chopper, L stores the energy during the time T_{on} of the chopper . When the chopper is off , v_0 =(E+ L . di/dt) will be more than the source voltage V_S . Because of this the diode D2 will be forward biased and begins conducting and hence the power starts flowing to the source. No matter the chopper is on or off the current I_0 will be flowing out of the load and is treated negative . Since V_O is positive and the current I_0 is negative , the direction of power flow will be from load to source. The load voltage V_0 = (E+L .di/dt) will be more than the voltage V_S so the type B chopper is also known as a step up chopper .



TYPE -C CHOPPER OR TWO-QUADRANT TYPE-A CHOPPER

Type C chopper is obtained by connecting type –A and type –B choppers in parallel. We will always get a positive output voltage V_0 as the freewheeling diode FD is present across the load. When the chopper is on the freewheeling diode starts conducting and the output voltage v_0 will be equal to V_S . The direction of the load current i_0 will be reversed. The current i_0 will be flowing towards the source and it will be positive regardless the chopper is on or the FD conducts. The load current will be negative if the chopper is or the diode D2 conducts. We can say the chopper and FD operate together as type-A chopper in first quadrant. In the second quadrant, the chopper and D2 will operate together as type –B chopper.

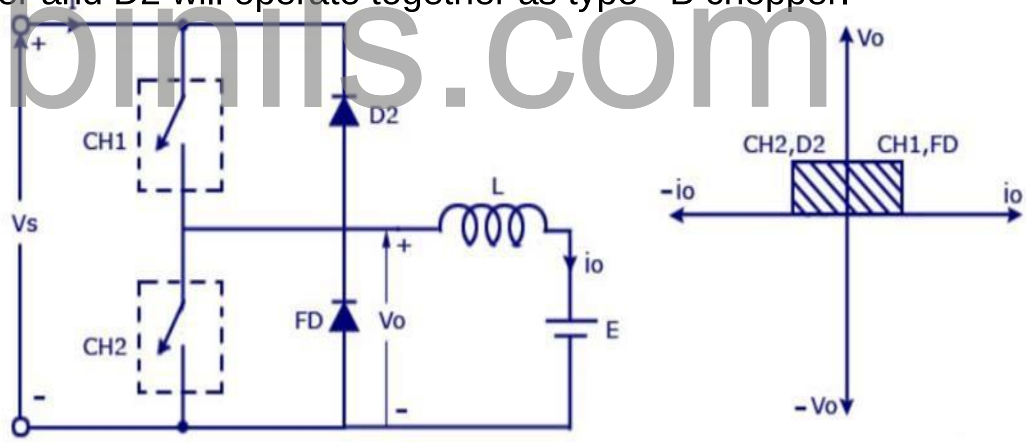
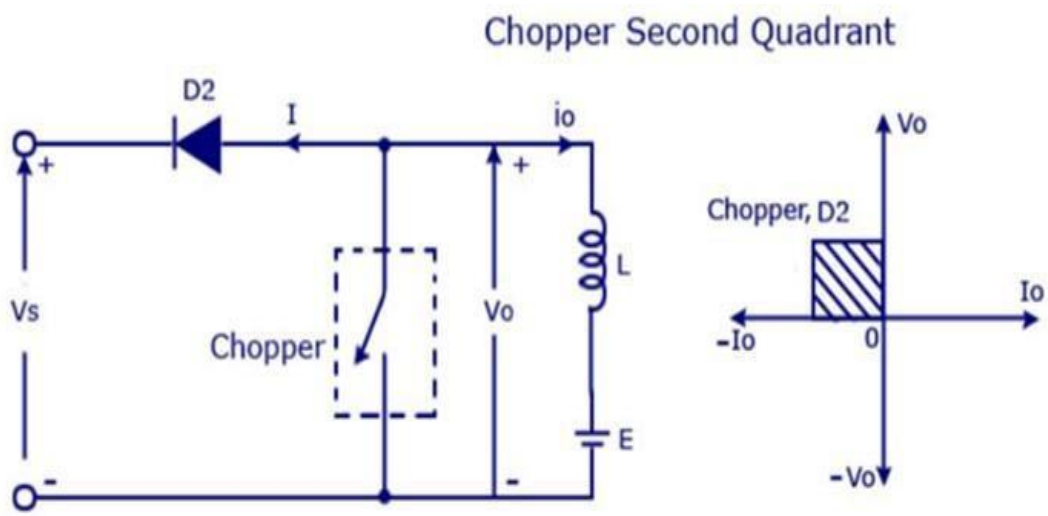


Figure 3.4.3 Type -C Chopper Or Two-quadrant Type-A Chopper

The average voltage will be always positive but the average load current might be positive or negative. The power flow may be life the first quadrant operation ie from source to load or from load to source like


Chopper Second Quadrant
D2
I
io
+
Vs
-
Chopper
Vo
+
-
L
E
Vo
Chopper, D2
-Io
0
Io
-Vo

the second quadrant operation. The two choppers should not be turned on simultaneously as the combined action my cause a short circuit in supply lines. For regenerative braking and motoring these type of chopperconfiguration is used.

TYPE D CHOPPER OR TWO-QUADRANT TYPE –B CHOPPER

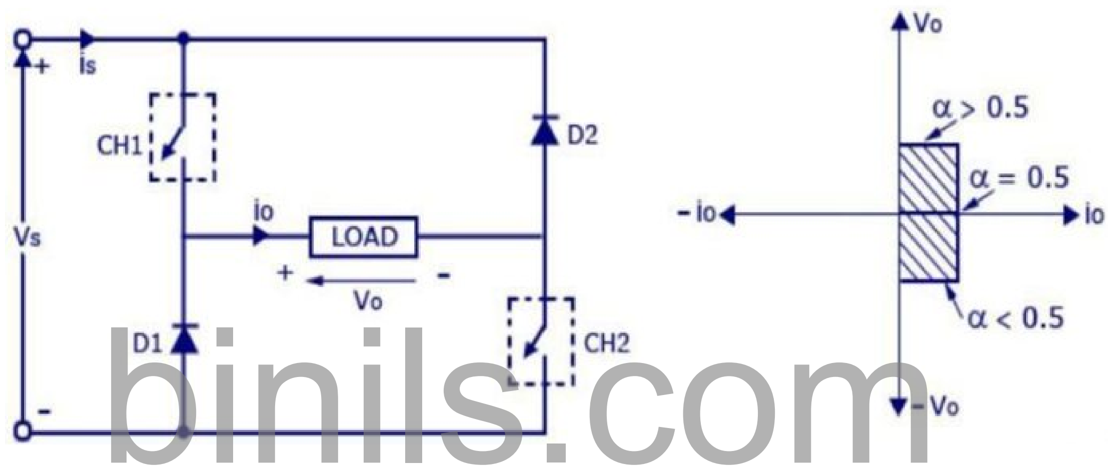


Figure 3.4.3 Type D Chopper Or Two-quadrant Type-B Chopper

- The circuit diagram of the type D chopper is shown in the above figure. When the two choppers are on the output voltage v_0 will be equal to V_S .

- When $v_0 = – V_S$ the two choppers will be off but both the diodes D1 and D2 will start conducting. V_0 the average output voltage will be positive when the choppers turn-on the time T_{on} will be more than the turn off time T_{off} its shown in the wave form below. As the diodes and choppers conduct current only in one direction the direction of load current will be always positive.

- The power flows from source to load as the average values of both v_0 and i_0 is positive. From the wave form it is seen that the average value of V_0 is positive thus the forth quadrant operation of type D chopper is obtained.
- From the wave forms the Average value of output voltage is given by

$$V0 = (V_S T_{on} - V_S T_{off}) / T$$

$$= V_S.(T_{on} - T_{off}) / T$$

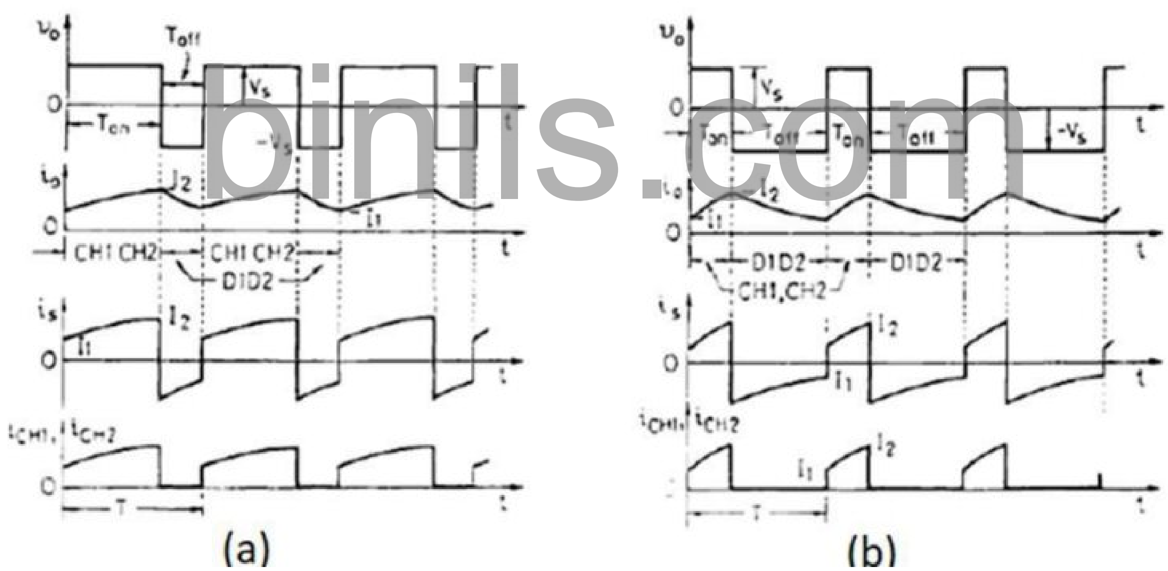


Figure 3.4.4 Type D Chopper waveform

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers Page: 256]

(a)Ton>Toff , Vo is Positive, First Quadrant Operation and

(b) Ton<Toff , Vo is Negative, Fourth Quadrant Operation

TYPE –E CHOPPER OR THE FOURTH-QUADRANT CHOPPER

- Type E or the fourth quadrant chopper consists of four semiconductor switches and four diodes arranged in antiparallel. The 4 choppers are numbered according to which quadrant they belong. Their operation will be in each quadrant and the corresponding chopper only be active in its quadrant.

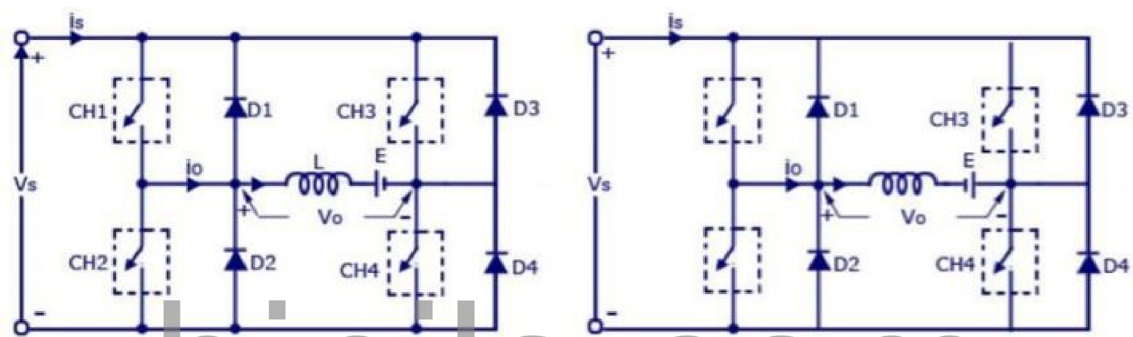


Figure 3.4.5 E-type Chopper with load emf E and E Reversed

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers Page: 257]

FIRST QUADRANT

During the first quadrant operation the chopper CH4 will be on . Chopper CH3 will be off and CH1 will be operated. AS the CH1 and CH4 is on the load voltage v_0 will be equal to the source voltage V_S and the load current i_0 will begin to flow. v_0 and i_0 will be positive as the first quadrant operation is taking place. As soon as the chopper CH1 is turned off, the positive current freewheels through CH4 and the diode D2 . The type E chopper acts as a step- down chopper in the first quadrant.

SECOND QUADRANT

In this case the chopper CH2 will be operational and the other three are kept off. As CH2 is on negative current will starts flowing through the inductor L . CH2 ,E and D4. Energy is stored in the inductor L as the chopper CH2 is on. When CH2 is off the current will be fed back to the source through the diodes D1 and D4. Here (E+L.di/dt) will be more than the source voltage V_S . In second quadrant the chopper will act as a step-up chopper as the power is fed back from load to source.

THIRD QUADRANT

In third quadrant operation CH1 will be kept off , CH2 will be on and CH3 is operated. For this quadrant working the polarity of the load should be reversed. As the chopper CH3 is on, the load gets connected to the source V_S and v_0 and i_0 will be negative and the third quadrant operation will takes place. This chopper acts as a step-down chopper.

FOURTH QUADRANT

CH4 will be operated and CH1, CH2 and CH3 will be off. When the chopper CH4 is turned on positive current starts to flow through CH4, D2 ,E and the inductor L will store energy. As the CH4 is turned off the current is feedback to the source through the diodes D2 and D3 , the operation will be in fourth quadrant as the load voltage is negative but the load current is positive. The chopper acts as a step up chopper as the power is fed back from load to source.

3.5 Switched Mode Regulators -BUCK REGULATOR

Switched Mode Regulators provide much greater power efficiency in DC-to-DC conversion than linear regulators, which are simpler circuits that lower voltages by dissipating power as heat, but do not step up output current. Switched mode regulators consists of energy storage elements along with dc-dc chopper circuits.To reduce voltage ripple, filters made of capacitors (or capacitors in combination with inductors) are normally added to such a converter's output (load-side filter)and input (supply-side filter.

Switched Mode Regulators are classified into Buck,Boost ,Buck-Boost Regulators.

BUCK REGULATOR

A buck converter (step-down converter) is a DC-to-DC power converter which steps down voltage while stepping up current from its input (supply) to its output (load).

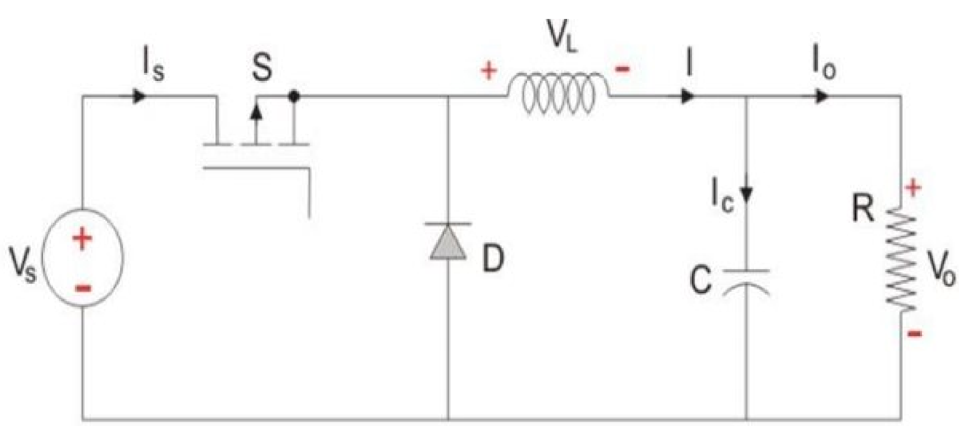


Figure 3.5.1 BUCK REGULATOR

[Source: "Power Electronics" *by* P.S.Bimbra, Khanna Publishers *Page: 492]*

MODE I: SWITCH IS ON, DIODE IS OFF

The voltage across the capacitance in steady state is equal to the output voltage. The switch is on for a time T_{ON} and is off for a time T_{OFF}. We define the time period, T, as T=Ton+Toff, and the switching frequency,

f= 1/T = chopping frequency

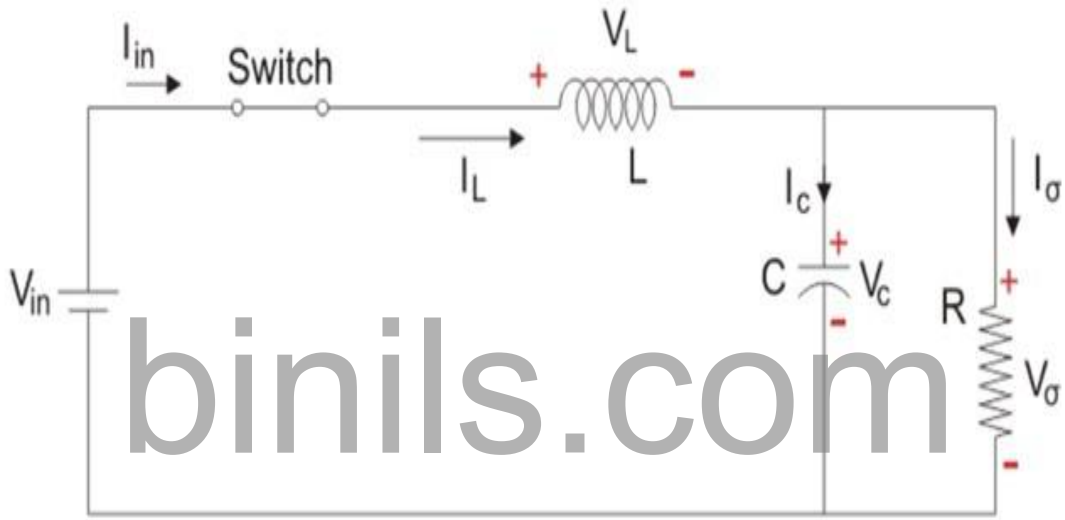


Figure 3.5.2 Buck converter- Mode II circuit diagram

[Source: "Power Electronics" *by* P.S.Bimbra, Khanna Publishers *Page: 492]*

MODE II: SWITCH IS OFF, DIODE IS ON

Here, the energy stored in the inductor is released and is ultimately dissipated inthe load resistance, and this helps to maintain the flow of current through the load. But for analysis we keep the original conventions to analyse the circuit using KVL.

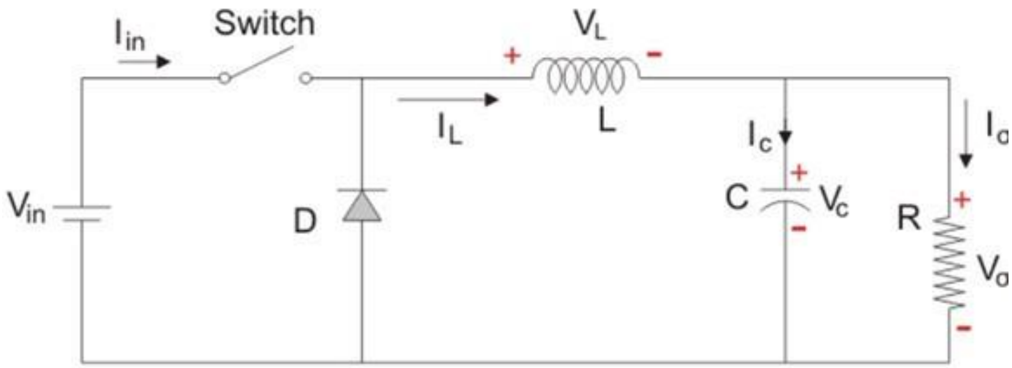


Figure 3.5.3 Buck converter- Mode II circuit diagram

[Source: "Power Electronics" *by* P.S.Bimbra, Khanna Publishers *Page: 493]*

Average load Voltage is given by

- $V_0 = T_{on}/(T_{on} + T_{off}) * V_s = (T_{on}/T)\ V =$
- $D\ V_s T_{on}$: on -time T_{off} : off- time
- Thus the load voltage can be controlled by varying the duty cycle D

$$V_0 = f.\,T_{on}\,.V_s$$

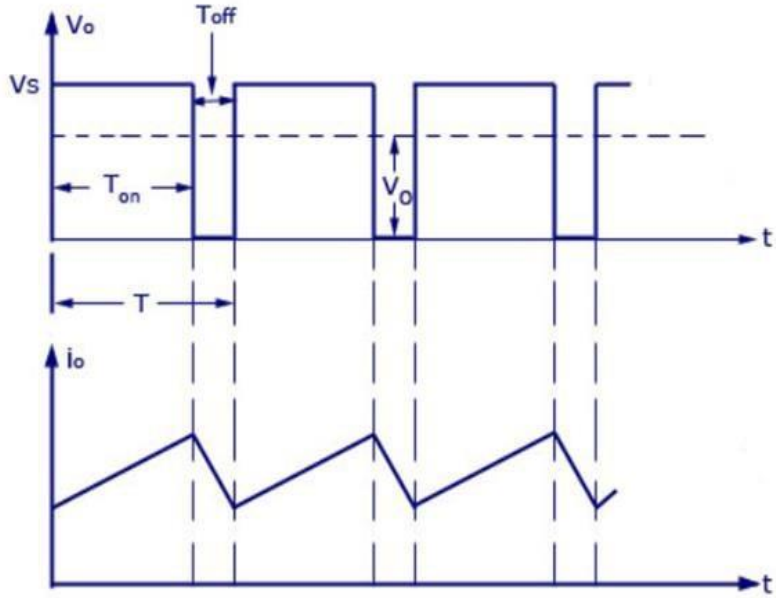


Figure 3.5.4 Buck converter Output Voltage and Current Waveforms

[Source: "Power Electronics" *by* P.S.Bimbra, Khanna Publishers *Page: 493]*

3.6 BOOST CONVERTER

- Boost converter which increases the input DC voltage to a specified DC output voltage. A typical Boost converter is shown below.

- Step-up chopper works as a step-up transformer on DC current.
- The working principle of a step up chopper can be explained from the above diagram. In the circuit, a large inductor L is connected in series to the supply voltage. Capacitor maintains the continuous output voltage to the load. The diode prevents the flow of current from load to source.

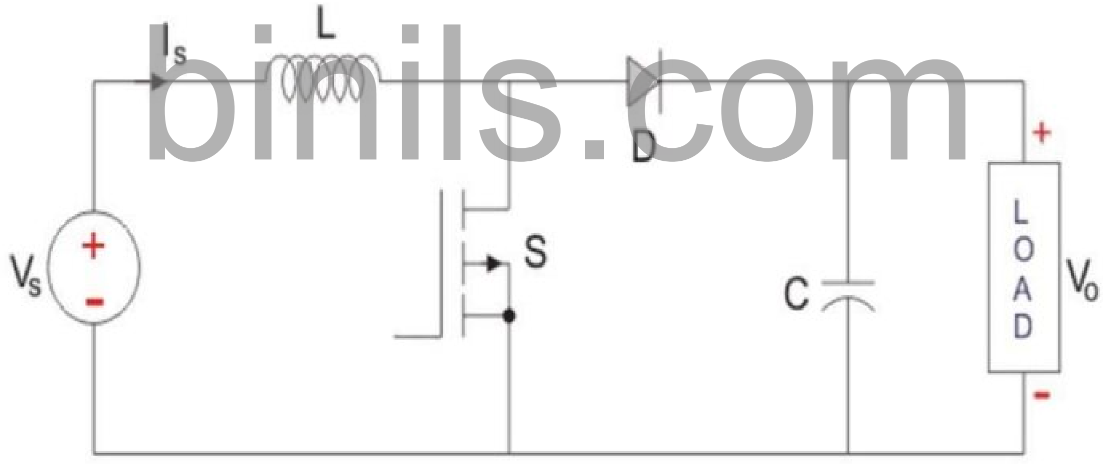


Figure 3.6.1 Block diagram of Boost convert

- The input voltage source is connected to an inductor. The solid-state device which operates as a switch is connected across the source. The second switch used is a diode. The diode is connected to a capacitor, and the load and the two are connected in parallel as shown in the figure above.

- The inductor connected to input source leads to a constant input current, and thus the Boost converter is seen as the constant current input source. And the load can be seen as a constant voltage source. The controlled switch is turned on and off by using Pulse Width Modulation(PWM). PWM can be time-based or frequency based. Frequency-based modulation has disadvantages like a wide range of frequencies to achieve the desired control of the switch which in turn will give the desired output voltage. Time-based Modulation is mostly used for DC-DC converters. It is simple to construct and use. The frequency remains constant in this type of PWM modulation.

The Boost converter has two modes of operation.

The first mode is when the switch is on and conducting.

MODE I : SWITCH IS ON, DIODE IS OFF

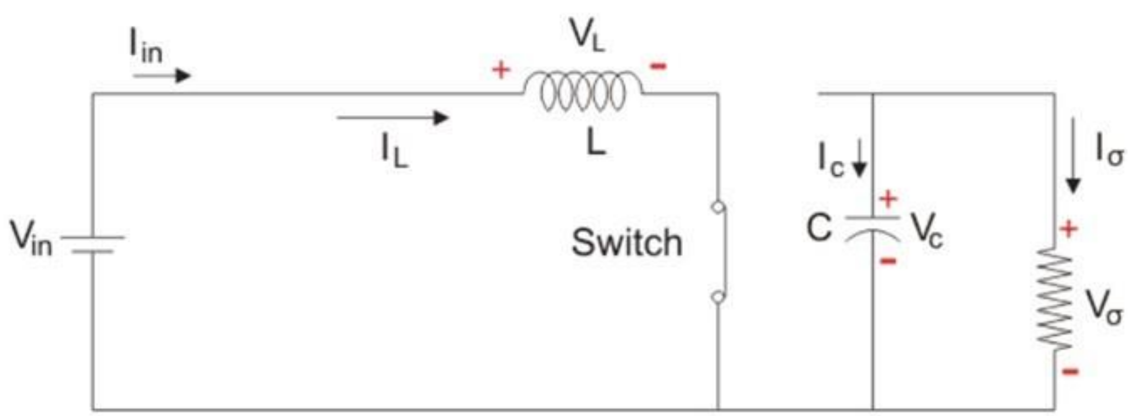


Figure 3.6.2 Boost converter- Mode I circuit

- The Switch is ON and therefore represents a short circuit ideally offering zero resistance to the flow of current so when the switch is ON all the current will flow through the switch and back to the DC input source. Let us say the switch is on for a time T_{ON} and is off for a time T_{OFF}. We define the time period, T, as T=Ton + Toff.

- When the chopper is turned ON the current through the inductance L will increase from I_1 to I_2. As the chopper is on the source voltage is applied to L that is $v_L = V_S$.

MODE II : SWITCH IS OFF, DIODE IS ON

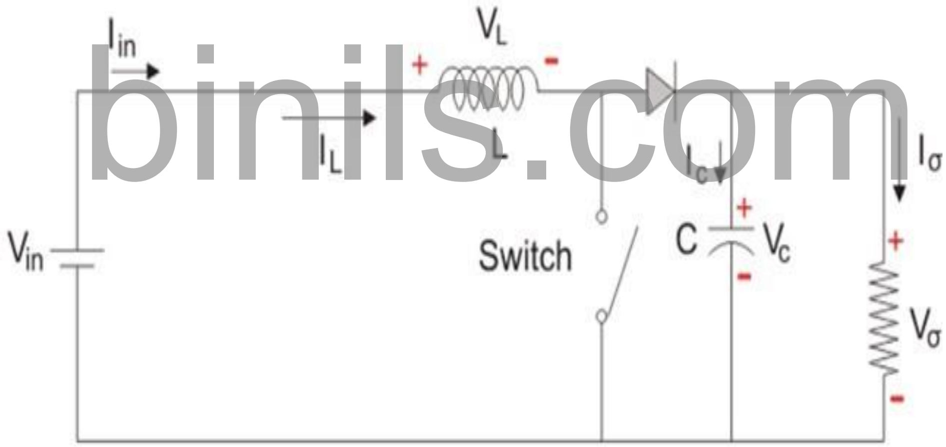


Figure 3.6.3 Boost converter- Mode II circuit diagram

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers Page: 280]

When the chopper is OFF, the KVL can bewritten as $v_L - V_0 + V_S = 0$ or $v_L = V_0 - V_S$

where v_L is the voltage across L. Variation of source voltage v_S, sourcecurrent I_S, load voltage v_0 and load current i_O is sketched in the fig .

Let us assume that the variation of output current is linear, the energyinput to inductor from the source, during the time period T_{on} , is

$$W_{in} = V_s (I_1+I_2/2) T_{on}$$

During the time T_{off} the chopper is off, so the energy released bythe inductor to the load is

$$W_{off} = (V_0-V_s)(I_1+I_2/2).T_{off}$$

Let us assume that the system is lossless, then the two energiessay W_{in} and W_{off} are equal.

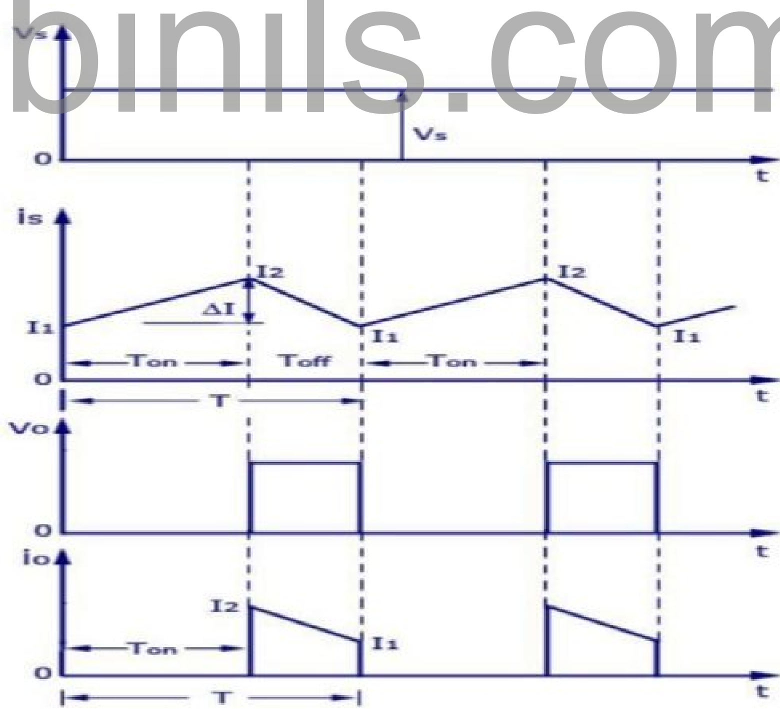


Figure 3.6.4 Boost converter Waveforms

Boost converter Output Voltage

So equating these two we will get

$V_S (I_1+I_2/2) T_{on} = (V_0-V_S)(I_1+I_2/2).T_{off}$

$V_S T_{on} = (V_0-V_S) T_{off}$

$V_0 T_{off} = V_S (T_{off} + T_{on}) = V_S .T$

$V_0 = V_S (T/T_{off}) = V_S \quad (T/T-T_{on}) = V_S (1/(1-D)$

From the above equation , we can see that the average voltage across the load can be stepped up by varying the duty cycle.

We know that D varies between 0 and 1. But as we can see from the equation above that if D = 1 then the ratio of output voltage to input voltage at steady state goes to infinity.

3.7 BUCK -BOOST CONVERTER

- **Buck Boost converter** which can operate as a DC-DC Step-Down converter or a DC-DC Step-Up converter depending upon the duty cycle.

A typical Buck-Boost converter is shown below

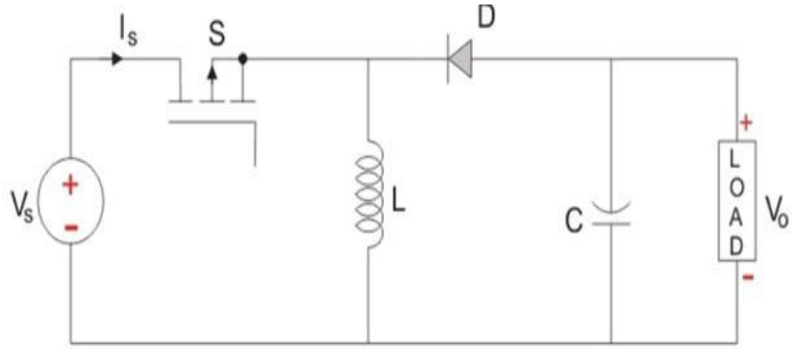


Figure 3.7.1 Buck- Boost converter circuit

- The input voltage source is connected to a solid state device. The second switch used is a diode. The diode is connected, in reverse to the direction of power flow from source, to a capacitor and the load and the two are connected in parallel as shown in the figure above.

- The controlled switch is turned on and off by using Pulse Width Modulation (PWM). PWM can be time based or frequency based. Frequency based modulation has disadvantages like a wide range of frequencies to achieve the desired control of the switch which in turn will give the desired output voltage. Time based Modulation is mostly used for DC-DC converters. It is simple to construct and use. The frequency remains constant in this type of PWM modulation.

The Buck Boost converter has two modes of operation.

MODE I : SWITCH IS ON, DIODE IS OFF

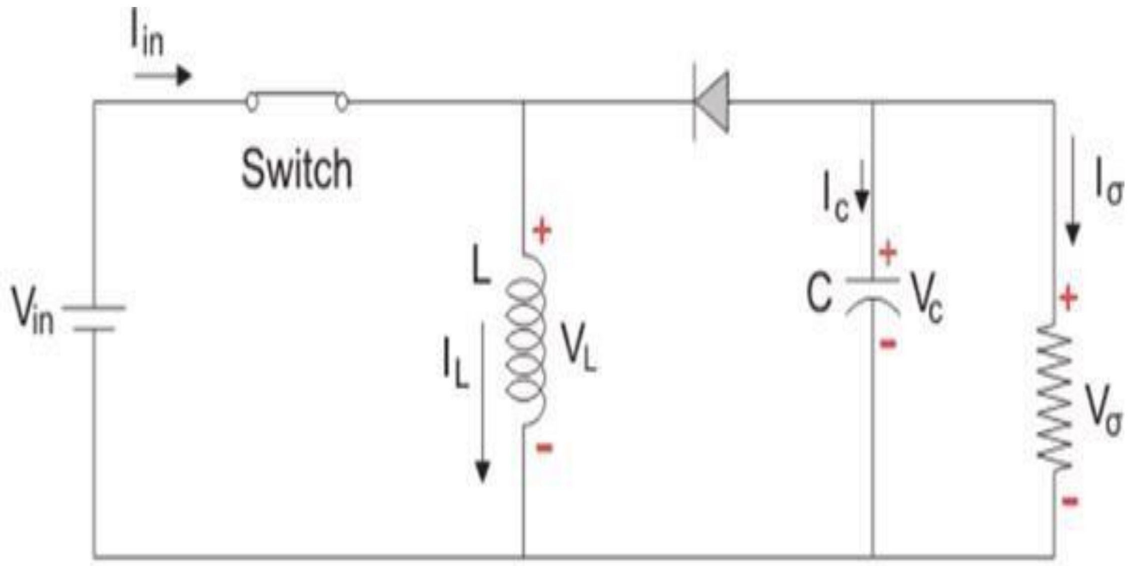


Figure 3.7.2 Buck- Boost converter- Mode I circuit

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers Page: 283]

- The Switch is ON and therefore represents a short circuit ideally offering zero resistance to the flow of current so when the switch is ON all the current will flow through the switch and the inductor and back to the DC input source. The inductor stores charge during the time the switch is ON and when the solid state switch is OFF the polarity of the Inductor reverses so that current flows through the load and through the diode and back to the inductor.
- So the direction of current through the inductor remains the same.

MODE II : SWITCH IS OFF, DIODE IS ON

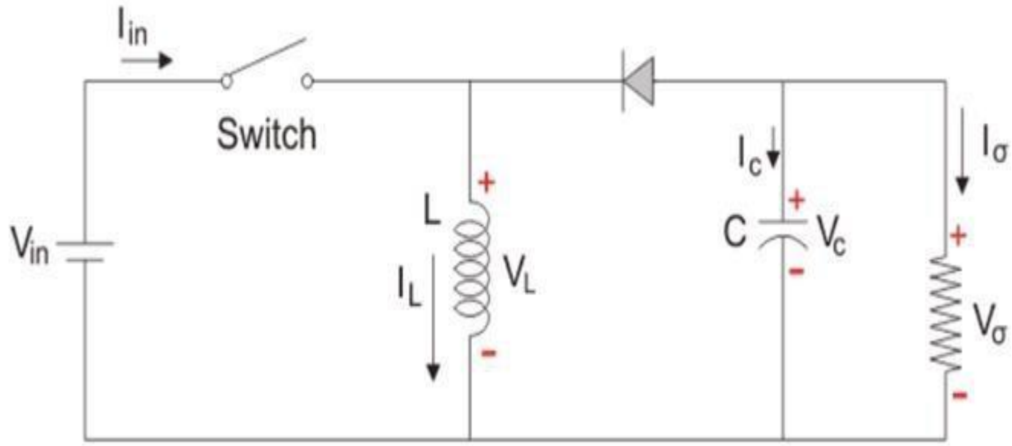


Figure 3.7.3 Buck- Boost converter- Mode II circuit diagram

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers Page: 283]

In this mode the polarity of the inductor is reversed and the energy stored in the inductor is released and is ultimately dissipated in the load resistance and this helps to maintain the flow of current in the same direction through the load and also step-up the output voltage as the inductor is now also acting as a source in conjunction with the input source.

3.8 Resonant converter

A resonant converter is a type of electric power converter that contains a network of inductors and capacitors called a "resonant tank", tuned to resonate at a specific frequency.

There are multiple types of resonant

converter: Series resonant inverter

Parallel resonant

inverter Class E

Resonant Converter

Class E Resonant

Rectifier

Zero Voltage Switching Resonant

Converter Zero Current Switching

Resonant Converter Two Quadrant ZVS

Resonant Converter Resonant dc-link

inverter

Need for resonant converter

- Hard switching is based on on/off– Switching losses– Electromagnetic Interference (EMI) because of high dv/dt and di/dtSMPS size decreases with increasing switching frequency.
- Target is to use as high switching frequency as possible – Switching losses are reduced if voltage and/or current are zero during switching.

ZCS Resonant-Switch Converter

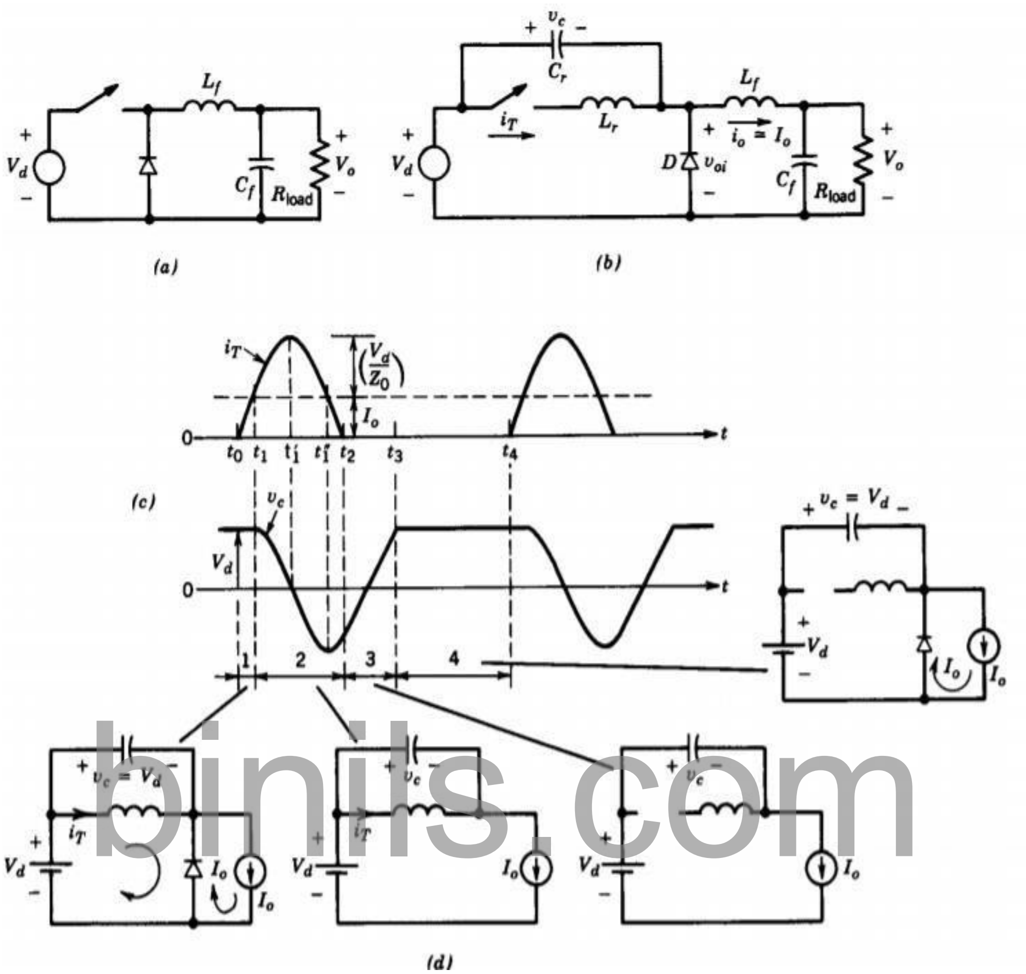


Figure 3.8.1 ZCS CONVERTER

Operation principle

- Current Io goes through the diode
- Cr is charged to the supply voltage Ud
- Switch is turned on –Diode D conducts untill at t1 current is equal to theload current
- Lr Cr is a resonant circuit discharging Cr

- At t2 current goes to zero and switch turns off
- Output current Io charges Cr to the supply
- voltage At t3 diode starts to conduct

ZVS Resonant-Switch Converter

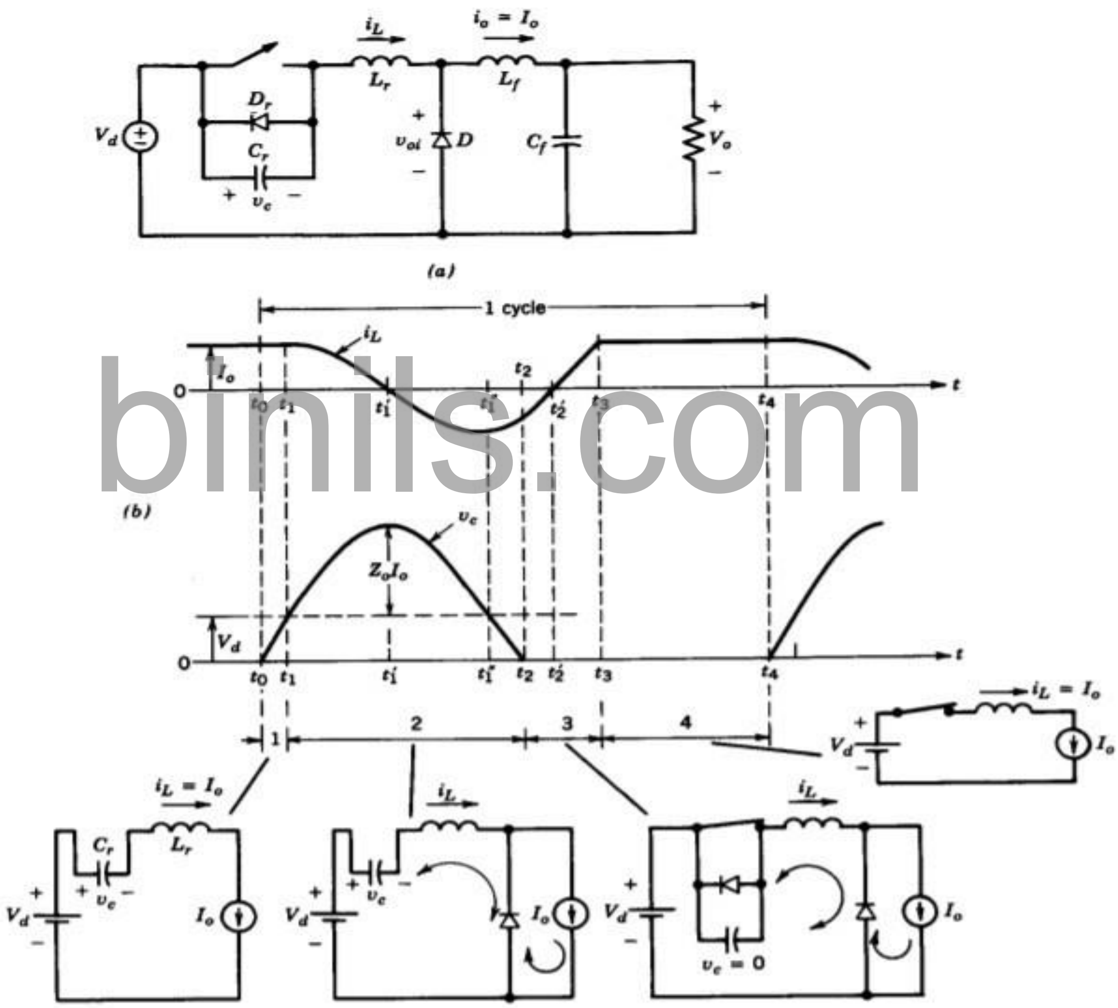


Figure 3.8.2 ZCS CONVERTER

[Source: "Power Electronics" *by* P.S.Bimbra, Khanna Publishers *Page: 295]*

3.9 BATTERY OPERATED VEHICLES

- **Definition:** The vehicles which get powered through a self-controlled battery for converting fuel into electricity, such type of vehicles are called battery powered vehicles or electrical vehicles. The lead acid battery is mostly used for powering the vehicles because of their low cost. The various types of DC and induction motors are used in battery powered vehicles.

Advantages of the battery powered vehicles:

It causes less pollution, It reduces noise pollution.

- The battery powered vehicles required less maintenance because it has no water cooling system to maintain, no filters, belts, or hoses to replace, or no oil to change.
- It is more reliable because of the presence of fuel injectors, compressors, pumps and valve.

Disadvantage of battery powered vehicles

- The battery powered vehicles are more expensive as compared tointernal combustion vehicles.
- The battery powered vehicles cannot go far on a single charge.
- Much longer time is required to charge a battery of battery poweredvehicles.

Let us consider a permanent magnet DC drive as shown in the figure below. The drive has chopper control and DC drive facility. The Lf and Cf are the filters which are used to filter the harmonics which is generated by the chopper. MS is the manual switch and RS is the reversal switch. The inductance L keep the ripple in motor current low.

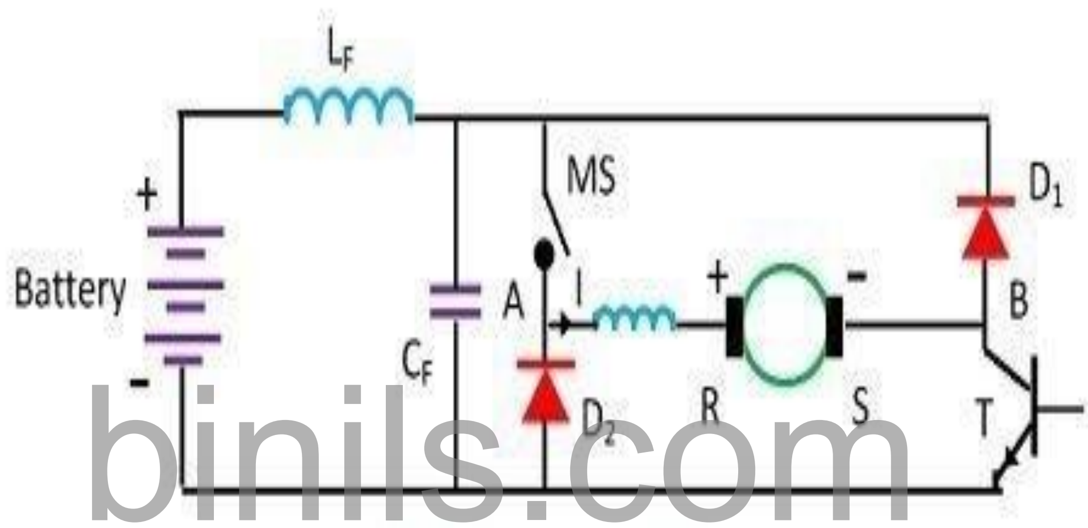


Figure 3.9.1 Dc Drive with Chopper Control

Motoring Operation

For motoring operation, the manual switch is kept close. The transistor switch operates at a constant frequency to obtaining variable DC voltage for starting and speed control. When the transistor is on the current flows through the source to L_f, MS, L, R, armature S and T. When the transistor is closed the current flows through S, D_1, MS, L and R.

Regenerative Braking Operation

For regenerative braking operation, the manual switch is kept open.The motor armature is reversed by the help of reversal switch which makes the B positive with respect to A. When the transistor is on the current flows through T, D_2 and L. When the transistor is closed the current flow through D_1, L_f and battery, D_2 and L and hence charge the battery.