Chapter-4 Power supplies

Switched Mode Power Supply

- Linear DC power supply operates on active region of the semiconductor device which increases on state power loss.

- Also in other power supplies based on phase-controlled rectifier needs large filter to reduce voltage ripple in the DC output voltage.

- This large filter makes the design of the power supply bulky.

- SMPS works on chopper, by operating the ON/OFF switch rapidly, as ac ripple frequency rises which can be easily filtered by L & C filter which are very small in size & weight.

- SMPS is based on chopper principle

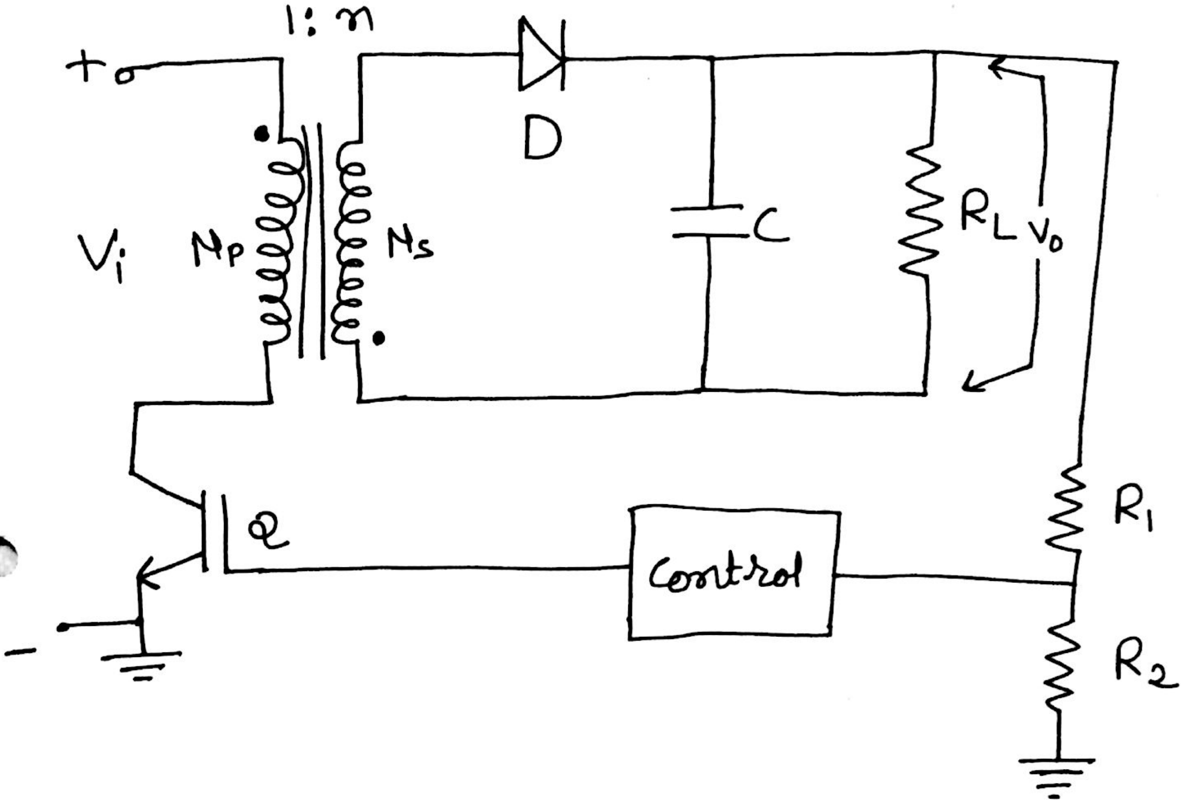
Advantages of SMPS

- Isolation between the source & load
- High power density for reduction of size & weight
- Controlled direction of power flow
- High conversion efficiency.
- Input & output waveforms with a low THD for small filters.
- Controlled power factor if the source is an ac voltage.

Different Topologies of SMPS (Isolated)

- Flyback converter (Buck-Boost)
- Forward converter (Buck)
- Push-pull converter (Buck)
- Half bridge converter (Buck)
- Full bridge converter (Buck)

Flyback Converter (Buck-Boost Based Isolated converter)



- Flyback converter is most popular converter
- This converter has very least component count.
- This works on buck-boost converter topology.
- The dot polarities on winding is introduce to measure the o/p voltage in the conventional positive sense.
- There are two switches Q & D, both are operated out of phase, observed by dot polarities of two winding inductor.
- Two winding inductor (xmer) provides isolation between source & load.

There are two operating modes of the converter.

Mode-I Q is ON

↳ when switch Q is ON the inductor energy builds up for the period KT.

where K = duty cycle = $\frac{T_{ON}}{T}$

T = Total time

$T_{ON} = T - T_{OFF}$

$T_{ON} = KT$

$T_{OFF} = T - T_{ON}$

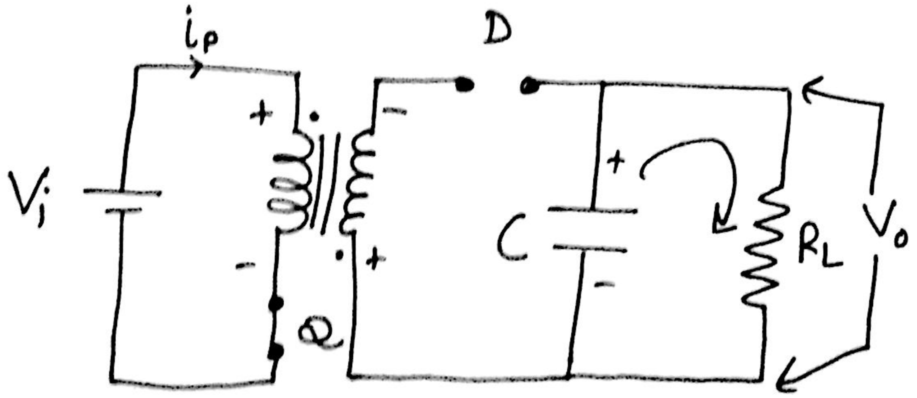
$= T - KT$

$T_{OFF} = (1-K)T$

↳ During this mode inductor energy builds up as it now directly connected to source V_i.

↳ During this time output voltage is supplied by capacitor C by discharging it through load.

↳ Diode D is reversed biased.



↳ $V_1 = V_i$

$V_2 = V_i n$

↳ There is no energy transferred from i/p to load.

↳ $i_p = \frac{V_i t}{L_p}$ L_p = Magnetizing inductance

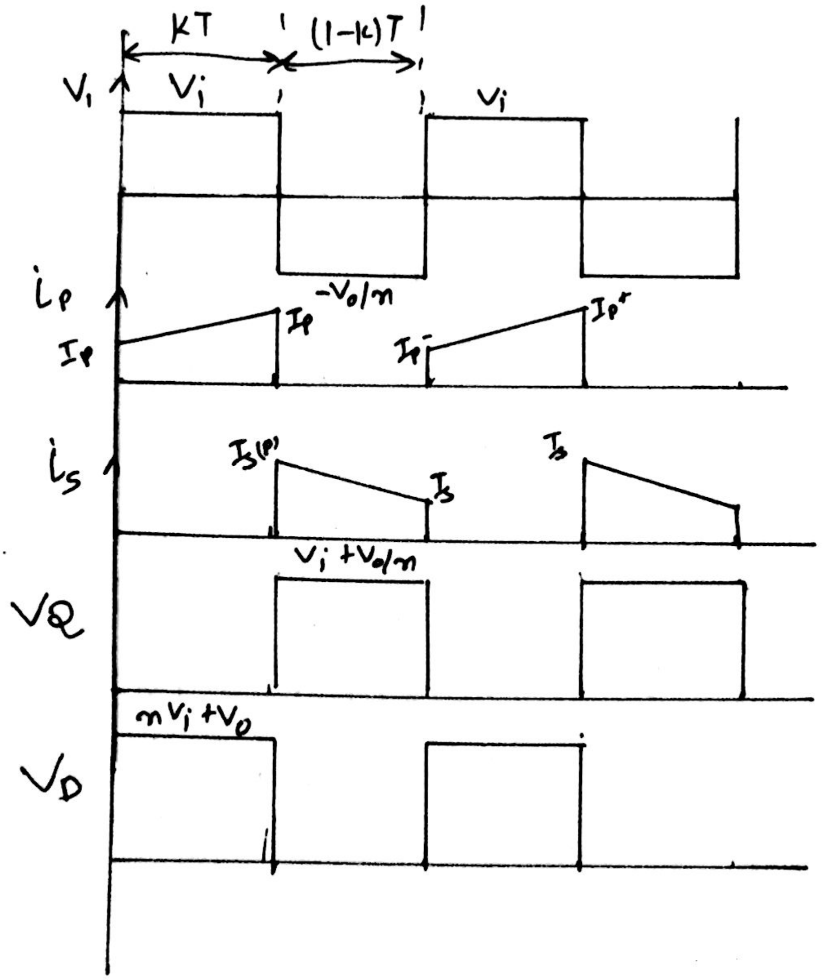
$t = KT$ → at the end

Peak Primary current

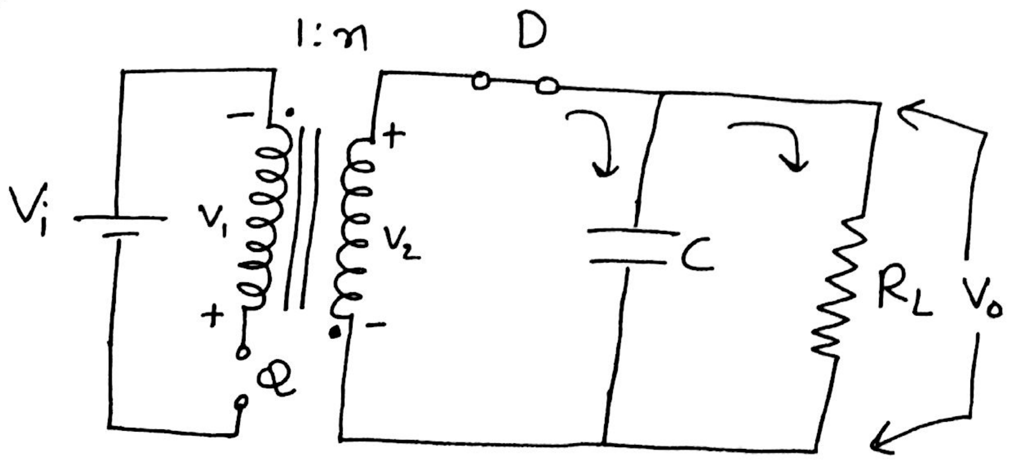
↳ $I_p = \frac{V_i KT}{L_p}$

Peak secondary current

$I_s = \frac{I_p}{n}$



Mode-II Q is OFF

- During this time switch Q is off.
- Due the reverse polarity Diode D is now forward biased
- The non dot end becomes positive
- The primary winding of inductor is now out of action.
- The secondary winding now discharges the energy stored in the core to the capacitor and load.
- 

- $V_2 = -V_o = -V_i n$
- $i_s = I_s - \frac{V_o t}{L_s}$ $\quad$ L_s = Magnetizing inductance of secondary

↳ During KT period switch Q is ON and the voltage across the primary is V_i.

↳ The current through primary is i_p.

↳ Voltage across secondary is nV_i.

↳ The voltage across D is $nV_i + V_o$

- ↳ During $(1-K)T$ period D is conducting.

↳ Voltage across the secondary is V_o.

↳ Voltage across the primary is $\frac{V_o}{n}$

↳ Voltage across Q is $V_i + \frac{V_o}{n}$

<u>Output voltage</u>

$$V_i T_{ON} = \frac{V_o}{n} T_{OFF}$$

$$V_o = n V_i \frac{T_{ON}}{T_{OFF}}$$

$$= n V_i \frac{KT}{(1-K)T}$$

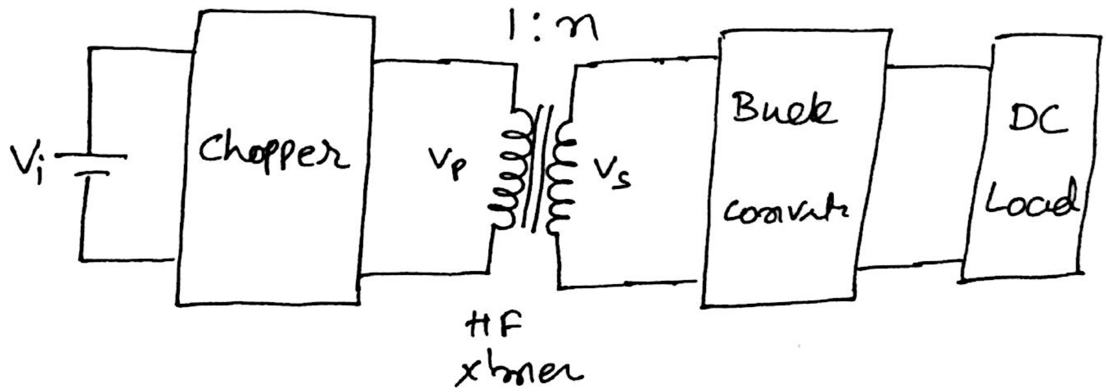
$$V_o = n V_i \left(\frac{K}{1-K}\right)$$

Buck Based Isolated Converter

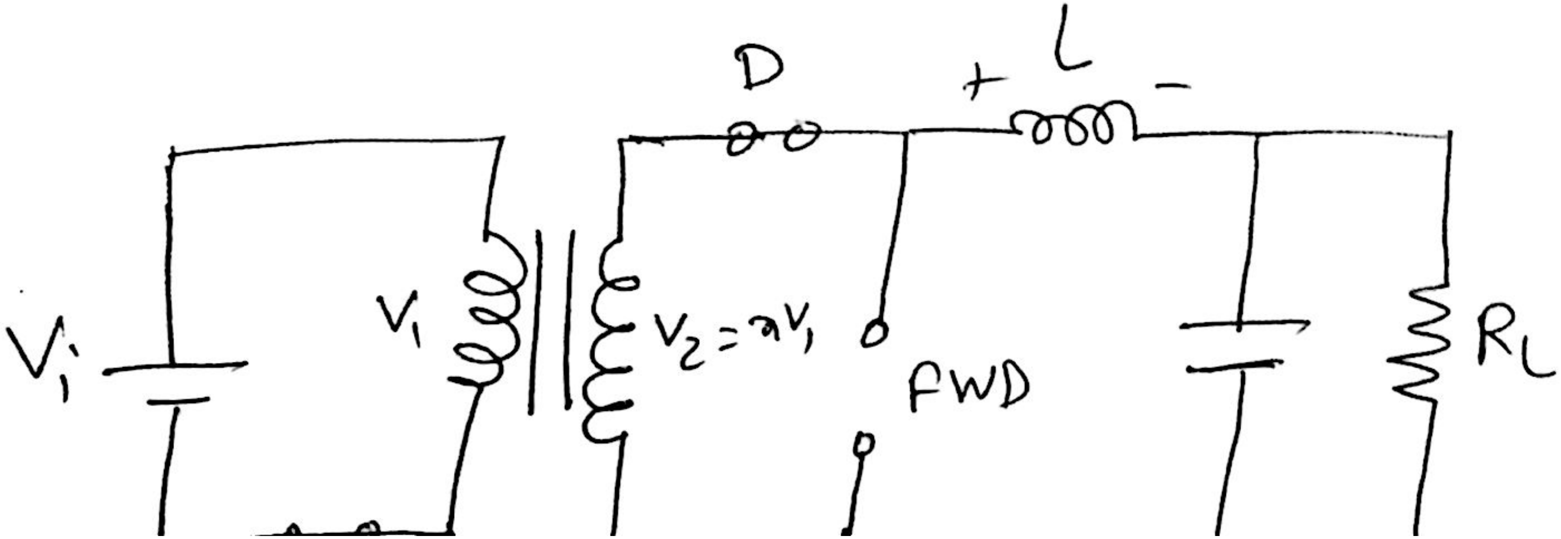
- Forward converter
- Push-pull converter
- Half-Bridge Converter
- Full Bridge converter

Forward Converter

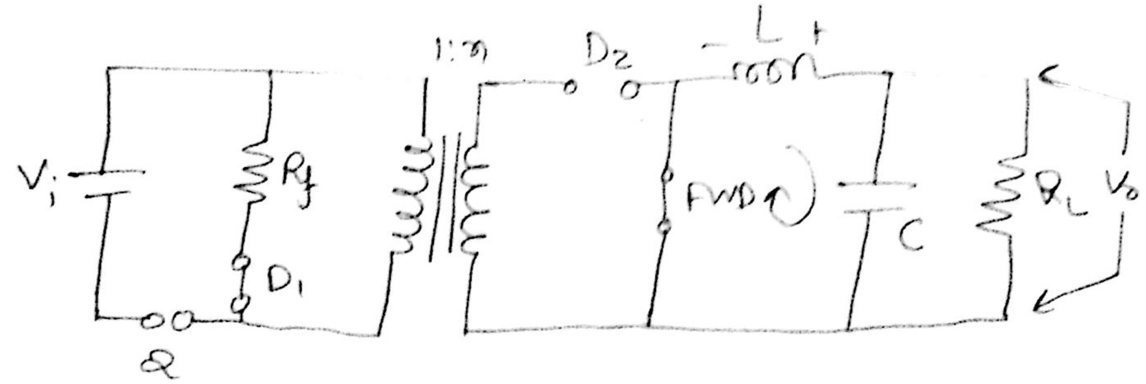
- Power flow is from the input source to the output through the transformer in only in one direction. the converter is called forward converter.



During Time KT Q is ON



During Time (1-k)T Q-off



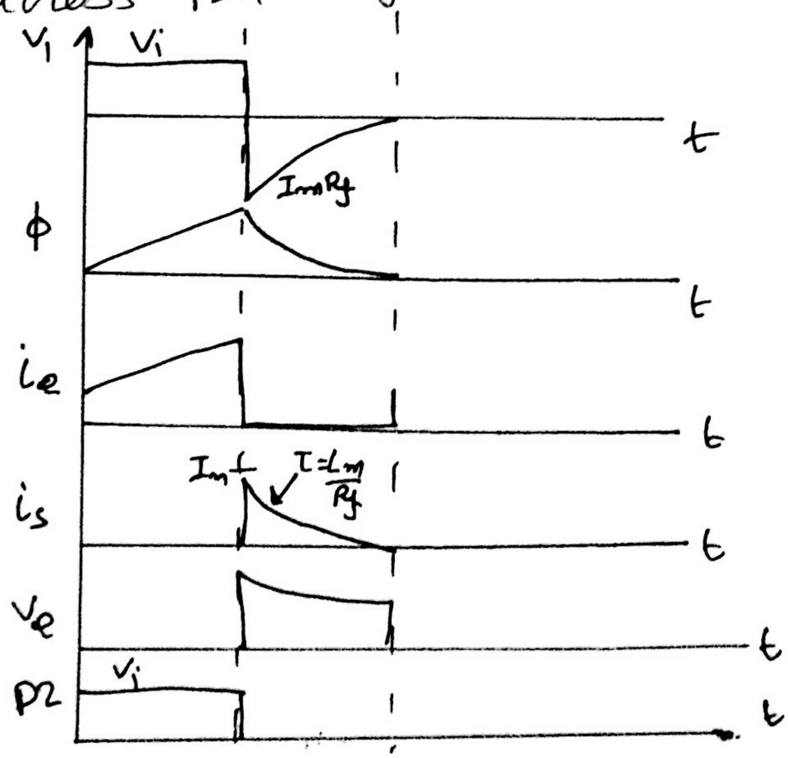
↳ During time (1-k)T switch is ~~closed~~ open

↳ No current is flowing through the secondary of transformer

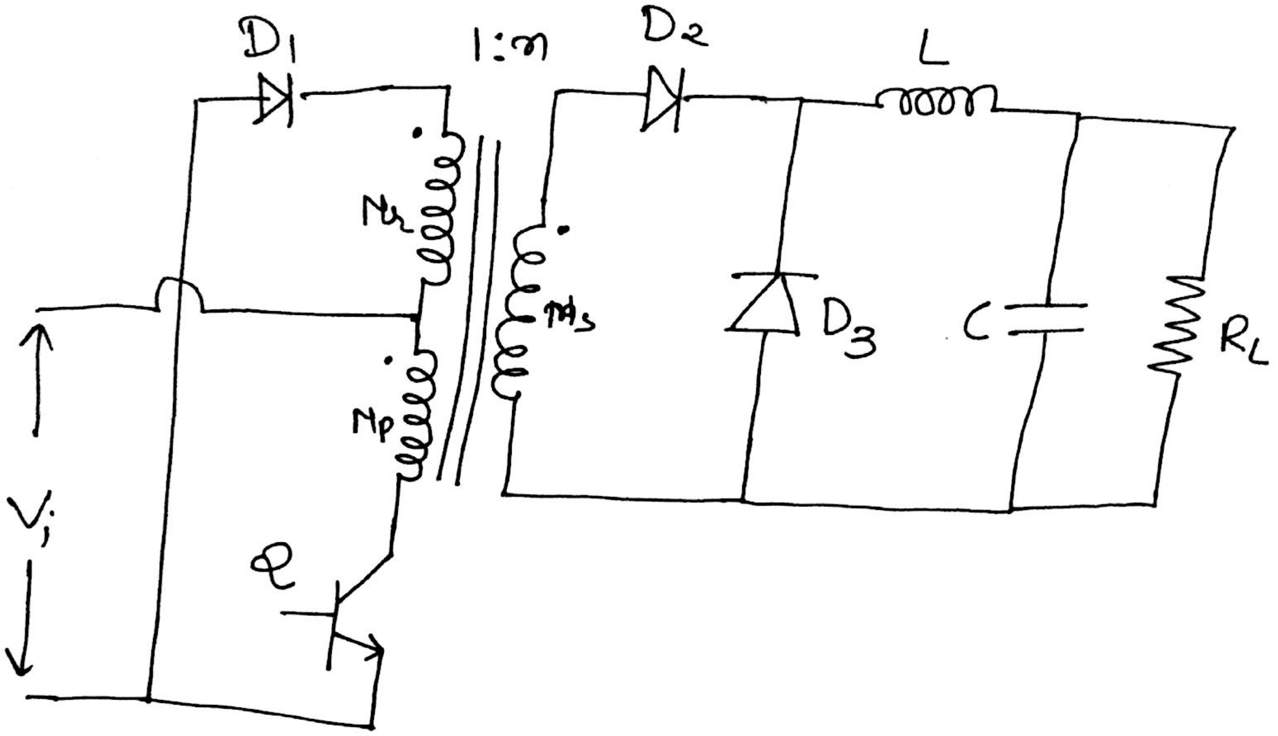
↳ Primary current is interrupted.

↳ Sudden cut off of primary current implies a negative di/dt and therefore voltage across primary is reversed.

↳



Forward converter (Demagnetizing winding)



- Here there are three windings used in x'mer.
- The x'mer core is reset by reset winding (Demagnetizing winding)
- The energy stored in the x'mer core is returned to the supply and the efficiency is increased.
- The dot on the secondary winding is so arranged that output diode D2 is forward biased when the voltage across primary is positive. When Q is on.

↳ D_2 is now forward biased due to positive voltage across secondary.

↳ The capacitor is charged and $v = nV_i$ voltage appears across Load.

↳ As D_1 is reversed biased no ~~vol~~ current flowing in the demagnetizing winding.

<u>Mode-II</u> (1-k)T

↳ During time (1-k)T the switch Q is off and D_2 is ON.

↳ The primary current is cut-off suddenly when Q is off.

↳ This makes a negative di/dt that will reverse the primary voltage polarity making the non-dot end positive.

↳ Non-dot end of demagnetizing winding +ve.

↳ This will cause the current to flow thro' the demagnetizing winding against the V_i.

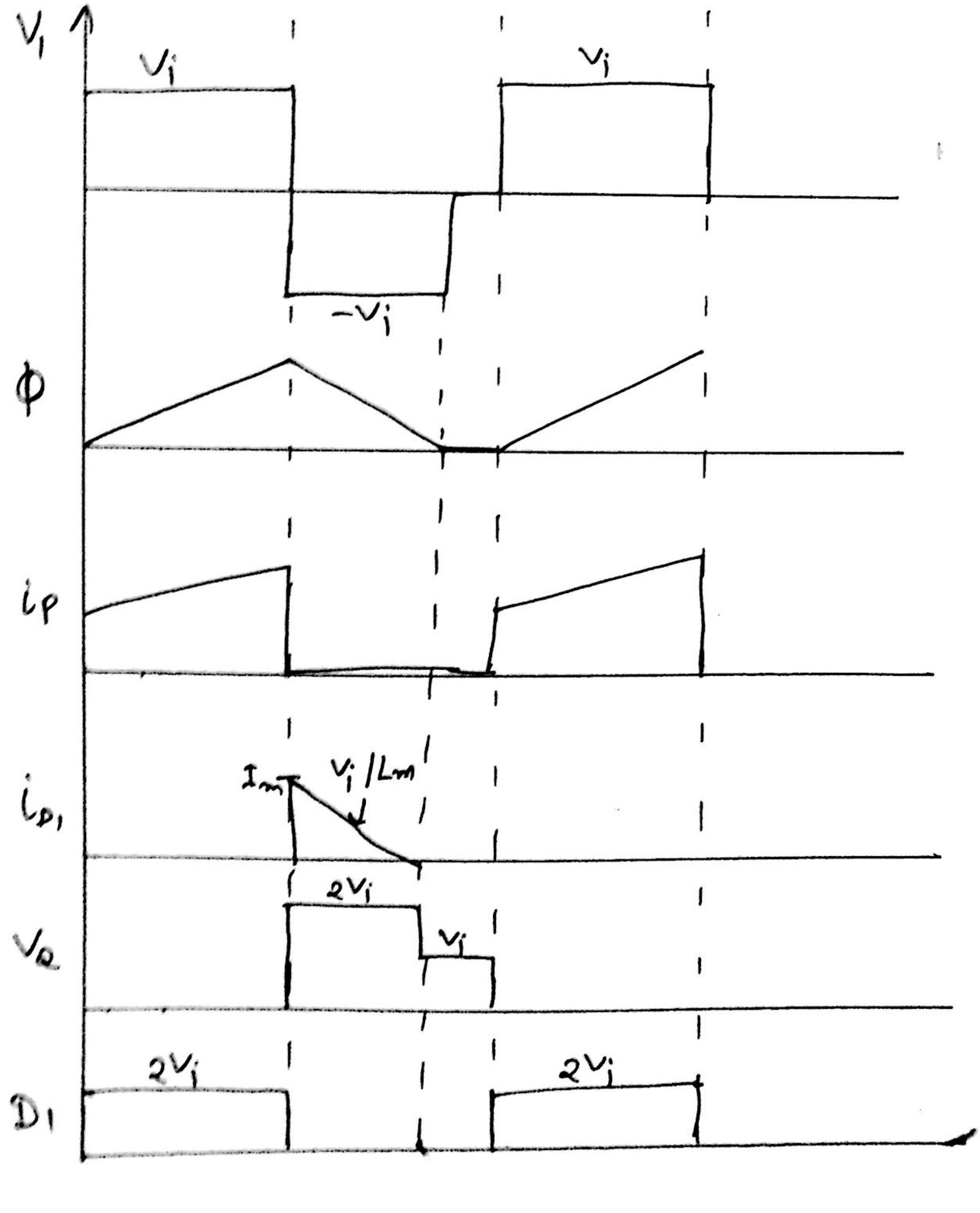
↳ The voltage across the demagnetizing winding will be V_i which will cause the flux in the core to decay linearly.

↳ If $N_s = N_p$ then for the flux that built up to maximum of ϕ_m during KT will decay to zero in exactly the same time when Q is off & D_2 is on.

↳ $N_s = N_p$, $(1-K)T > KT$ to insure flux will decay to zero.

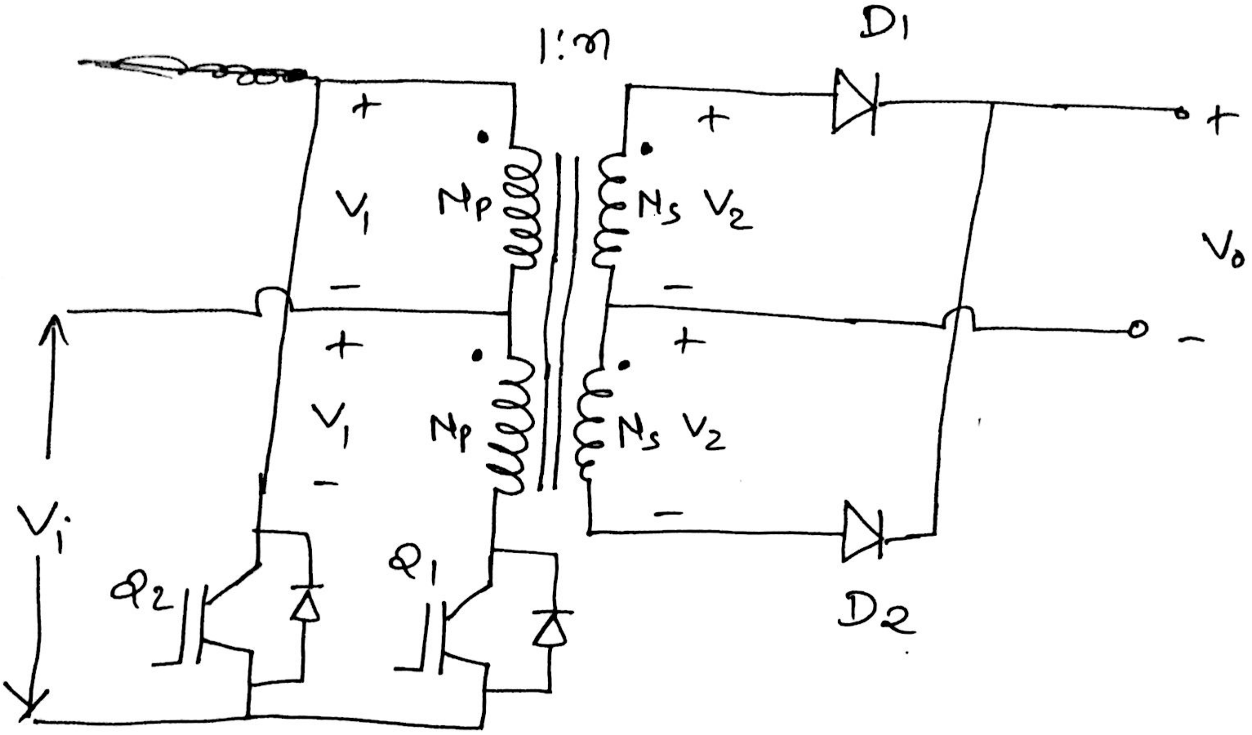
↳ It can be seen that $K < 0.5$.

i.e. maximum duty cycle is limited to <u>0.5</u>.



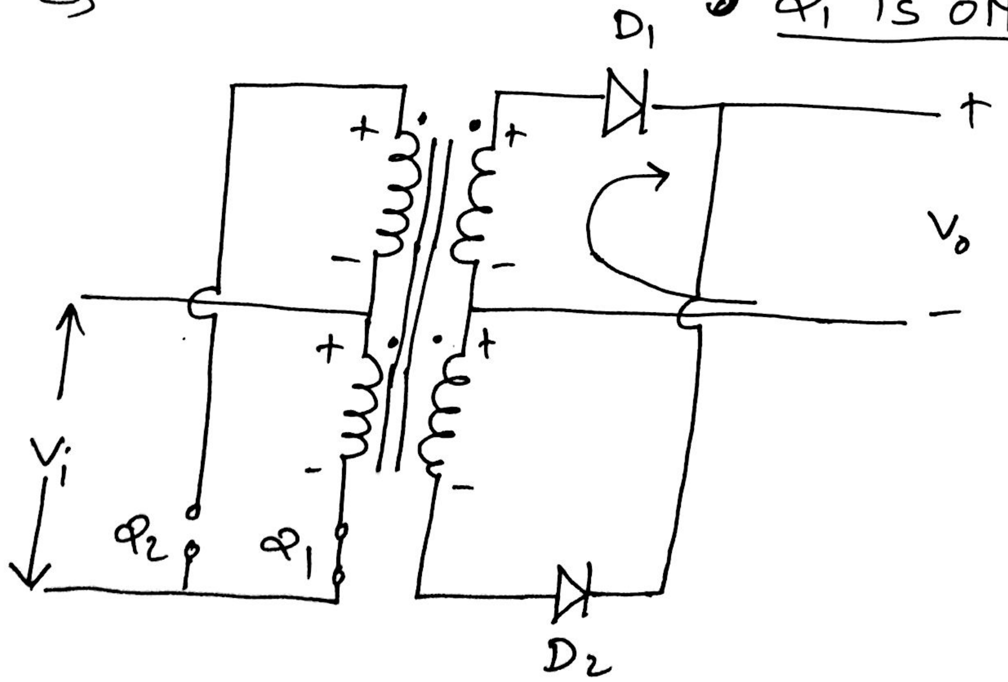
Push-Pull converter

- Forward converter utilizes only the positive half of the core magnetization as the magnetizing current & the core flux are unidirectional.
- Therefore the core is under utilized and core size for given power output is large than if it is utilized in both direction.
- The push-pull converter magnetize the core in both directions to better utilize the core.
- In push-pull converter two forward converters are operating in back to back, hence it is named push-pull converter.
- During KT one forward converter is transfering power to load ; during (1-K)T another forward converter is transfering power to load

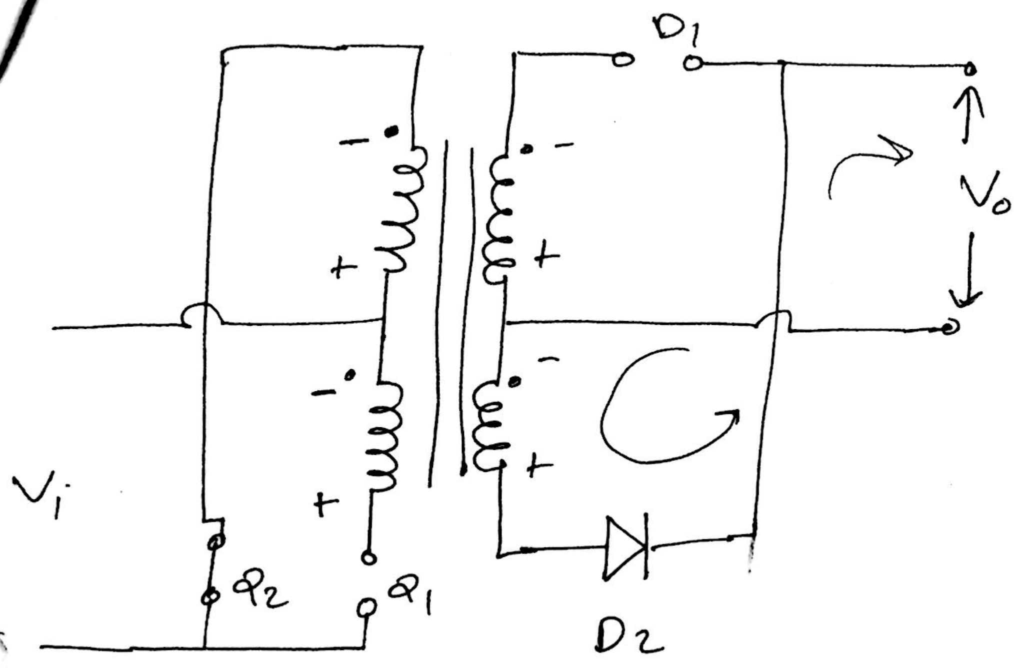


↳ Transformer is centered Tap and it consists of switch Q_1 & Q_2 in the primary side and rectifying diode D_1 & D_2 in the secondary side.

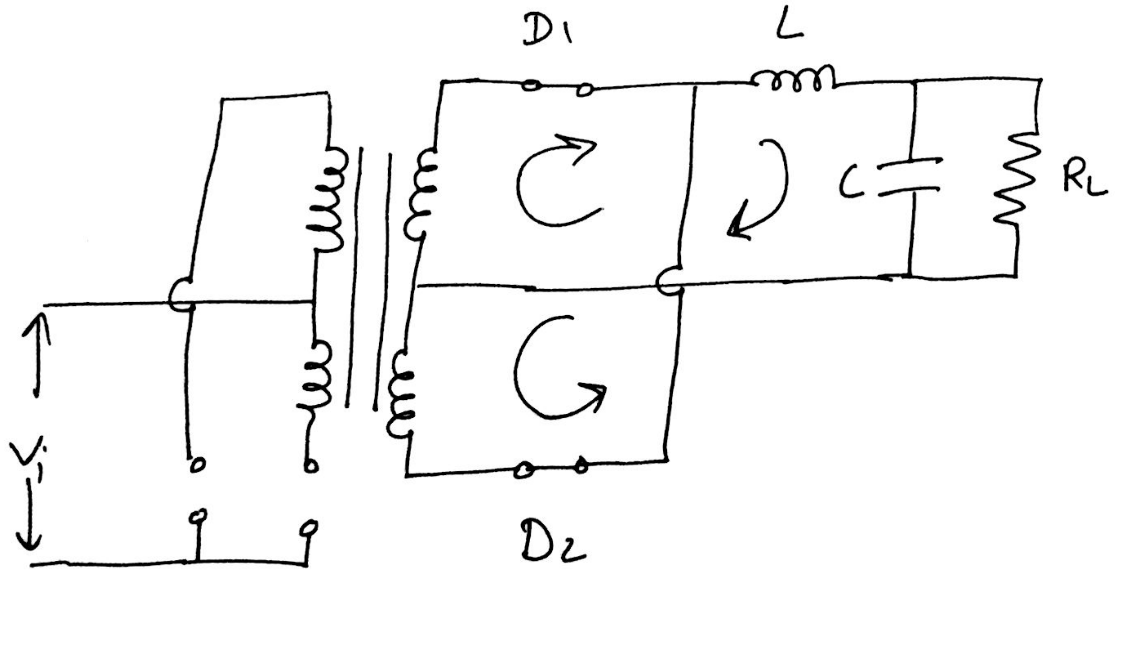
↳ Q_1 is ON

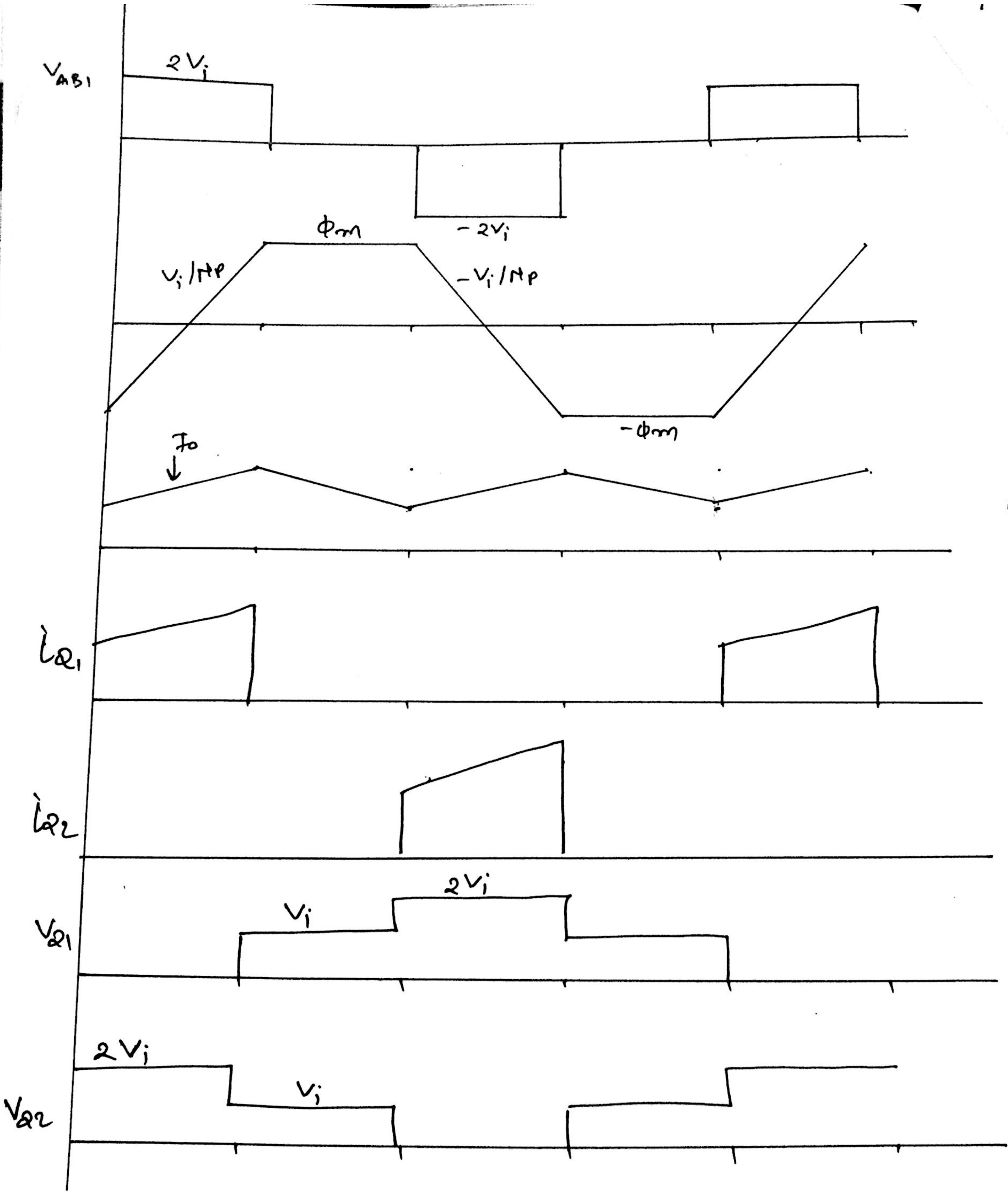


~~(1-K)T~~ ~~Q2 OFF~~ Q_2 ON



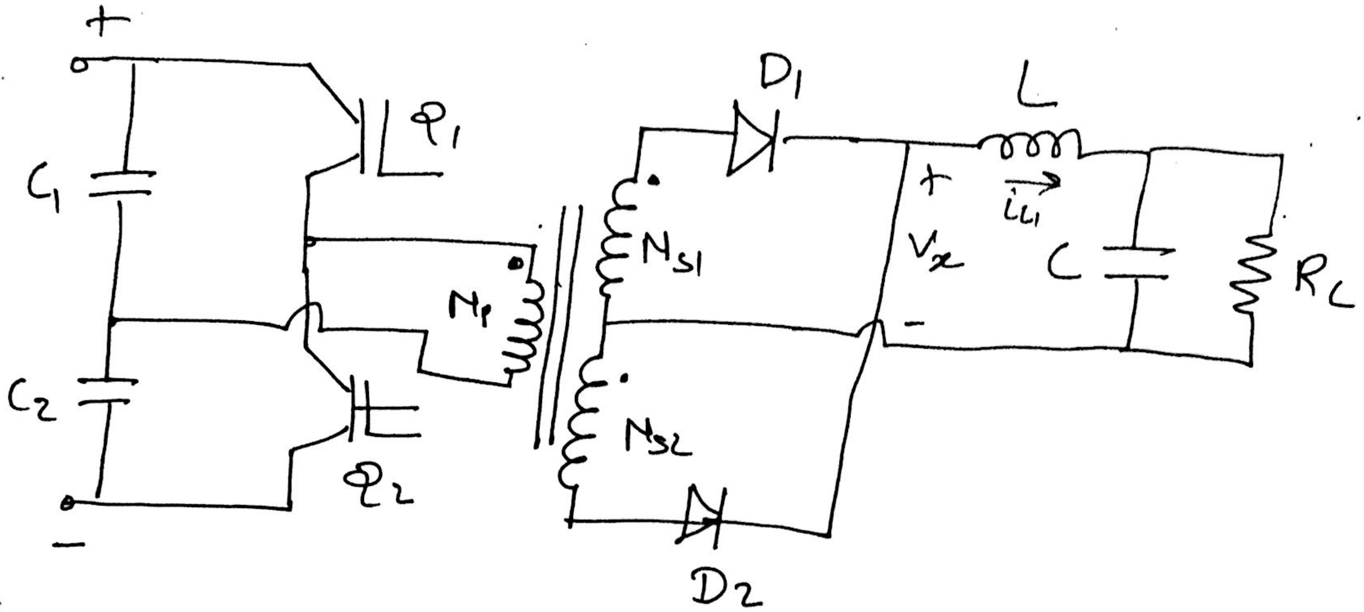
(1-K)T Period Q_1 & Q_2 OFF

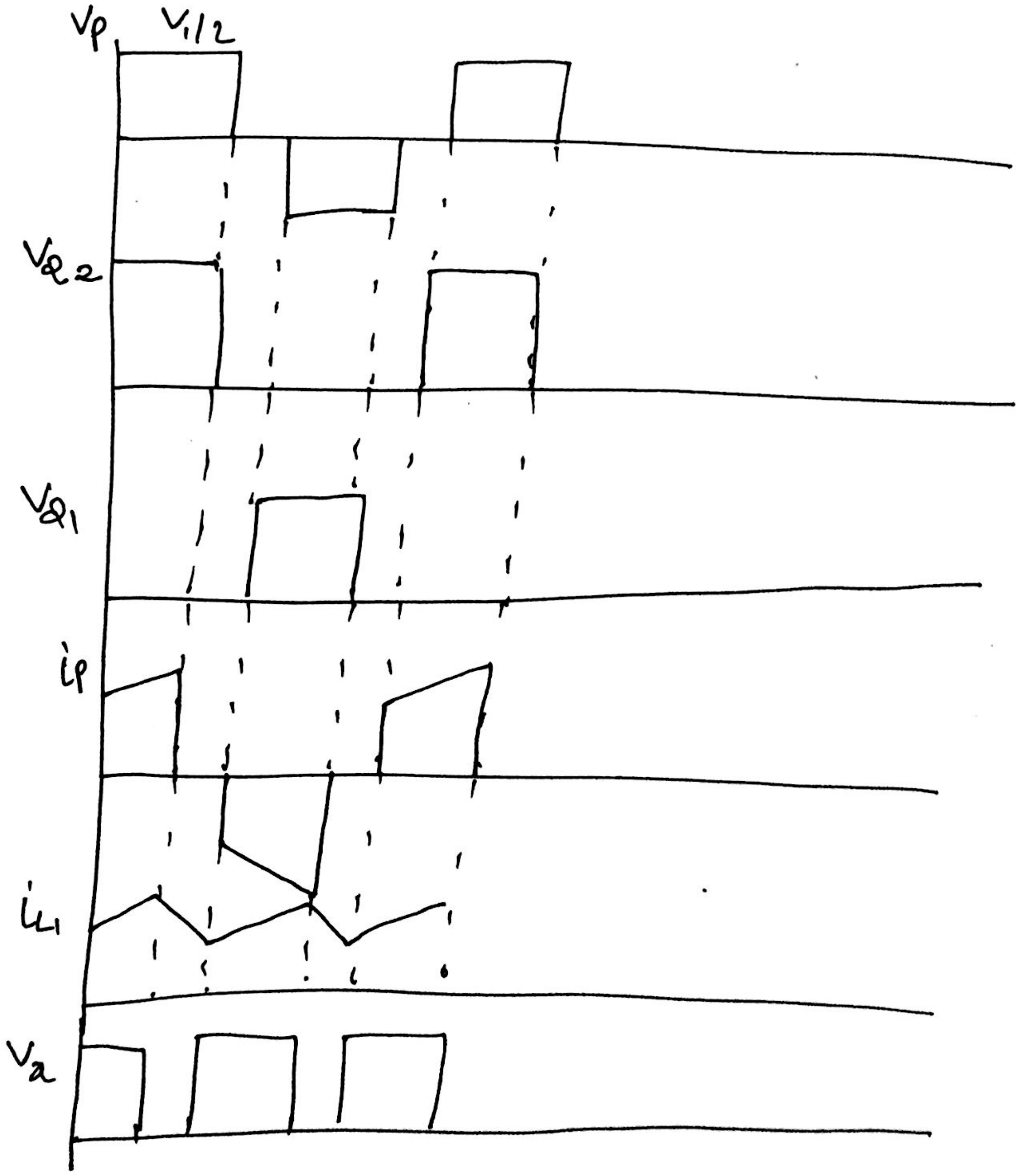




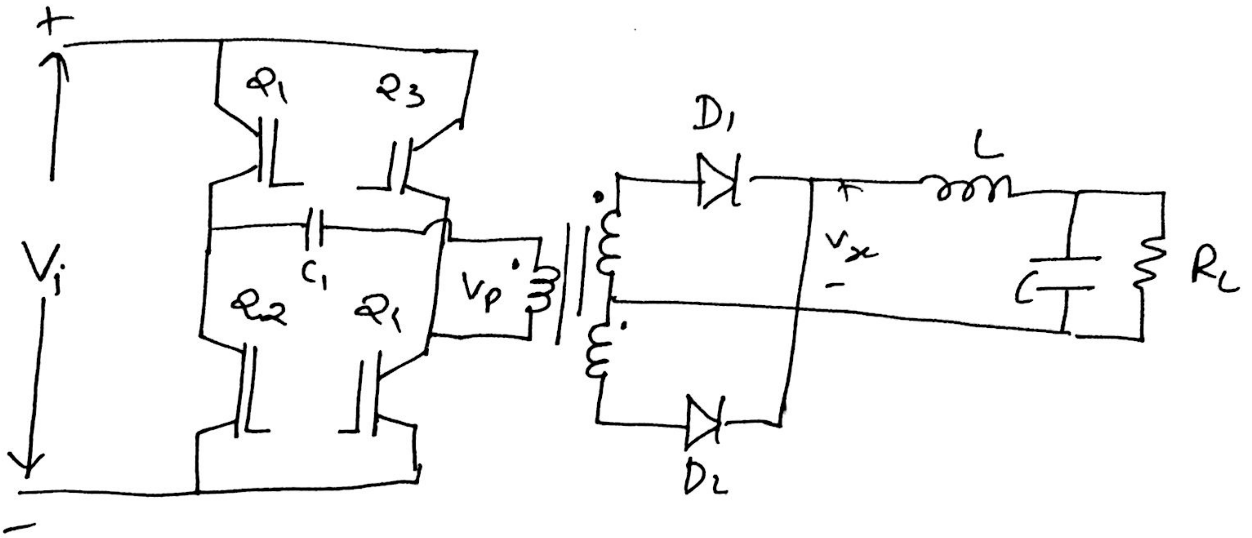
V_{AB1}
$2V_i$
$-2V_i$
Φm
V_i/Np
$-V_i/Np$
$-\Phi m$
Io
i_{Q1}
i_{Q2}
V_{Q1}
V_i
$2V_i$
V_{Q2}
$2V_i$
V_i

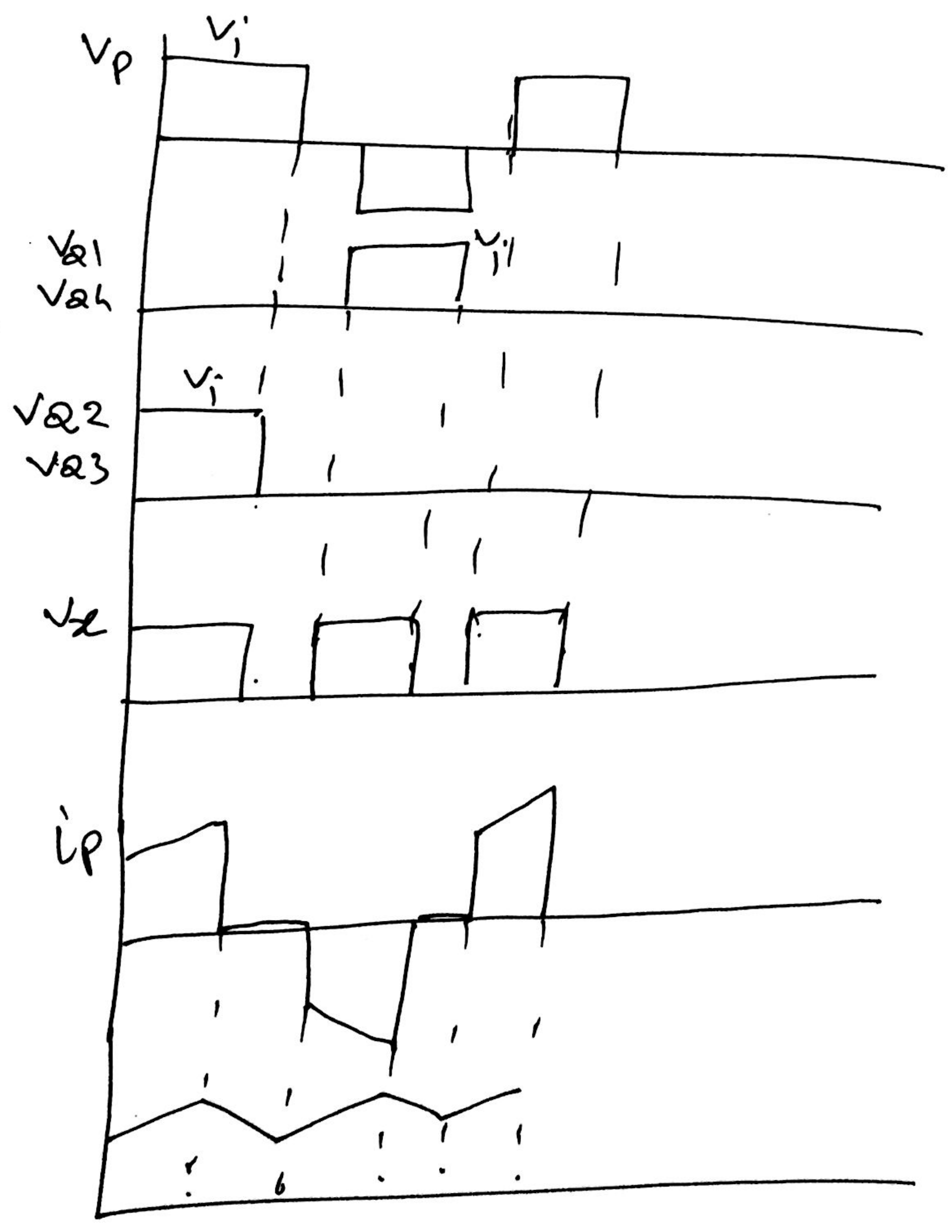
Half Bridge converter





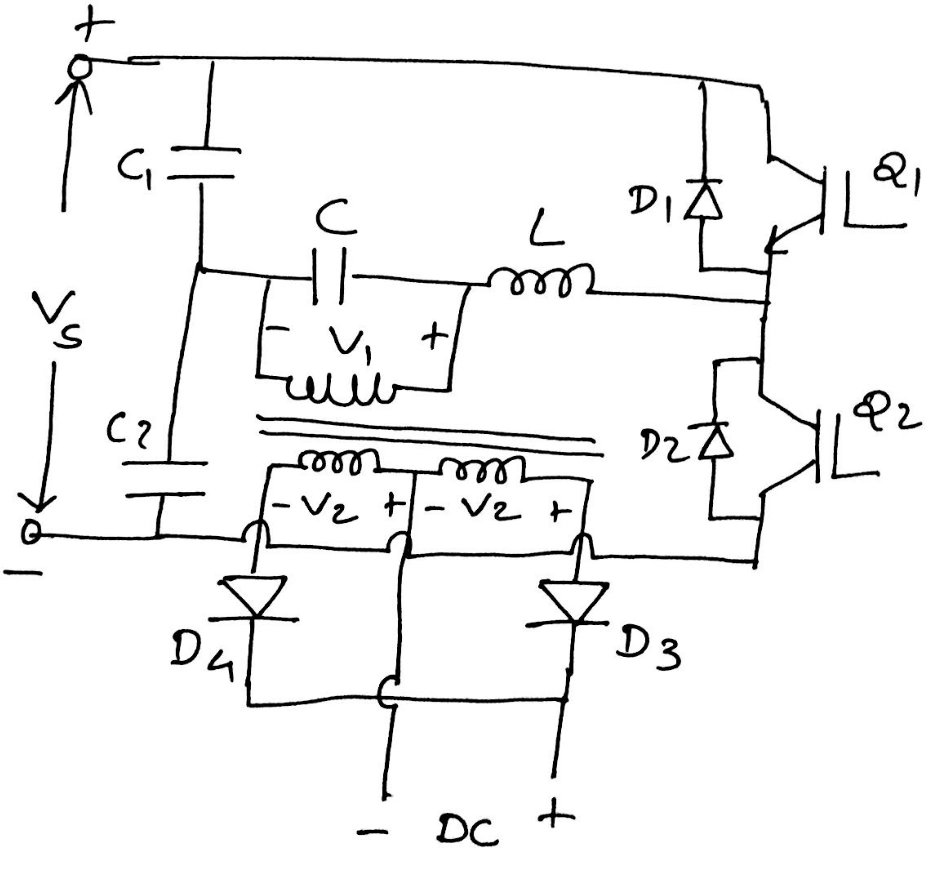
Full Bridge converter



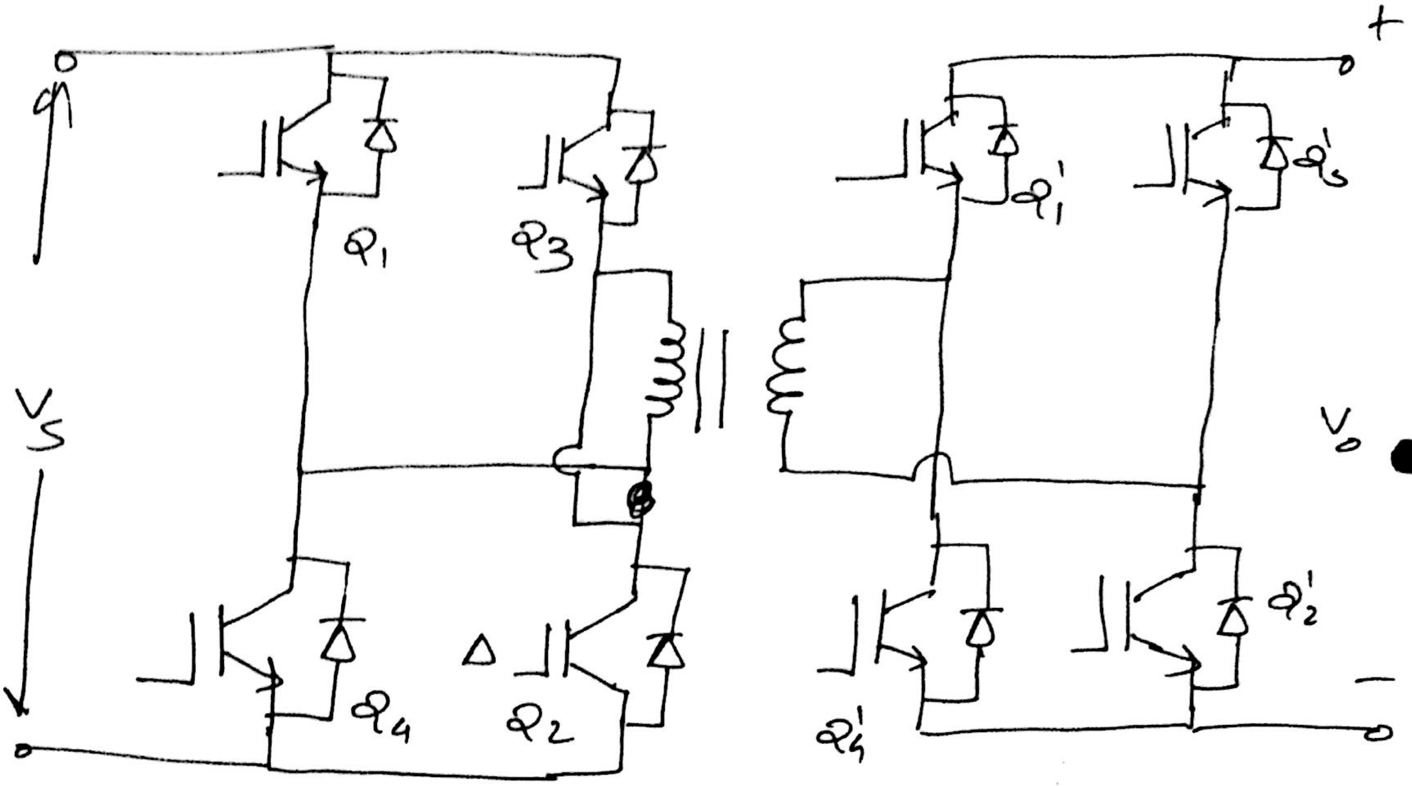


Resonant DC Power Supplies

- If the variation in DC output voltage is not wide, Resonant pulse inverter can be used.
- The inverter frequency could be same as resonant frequency.
- Inverter output voltage is sinusoidal.
- Due to resonant oscillations the x'mer is always reset and there are no DC saturation problems.



Bidirectional DC power supply



- In some applications such as Battery charger it is desirable to have bidirectional power flow capability.
- The direction of power flow depends on the values of V_o, V_s & turns ration n
- If $V_o < nV_s$ ⇒ Source to load

  If $V_o > nV_s$ ⇒ Load to source

Uninterruptible Power Supply

- The are some loads like
  - computers
  - Bio-medical instruments
  - surgical equipments
  - communication equipments
  - Security systems
  - Air Traffic controller

  requires a continuous, good quality power supply.

- These equipments (loads) ~~required~~ are known as critical (sophisticated) loads.
- These critical loads are very sensitive to the nature of power supply for their operation.
- These sensitive load requires a stand by power supply.
- These stand by power supplies are commonly known as uninterruptible power supply (UPS).
- UPS provides emergency power to a critical load when the utility main supply fails.

Introduction to UPS system

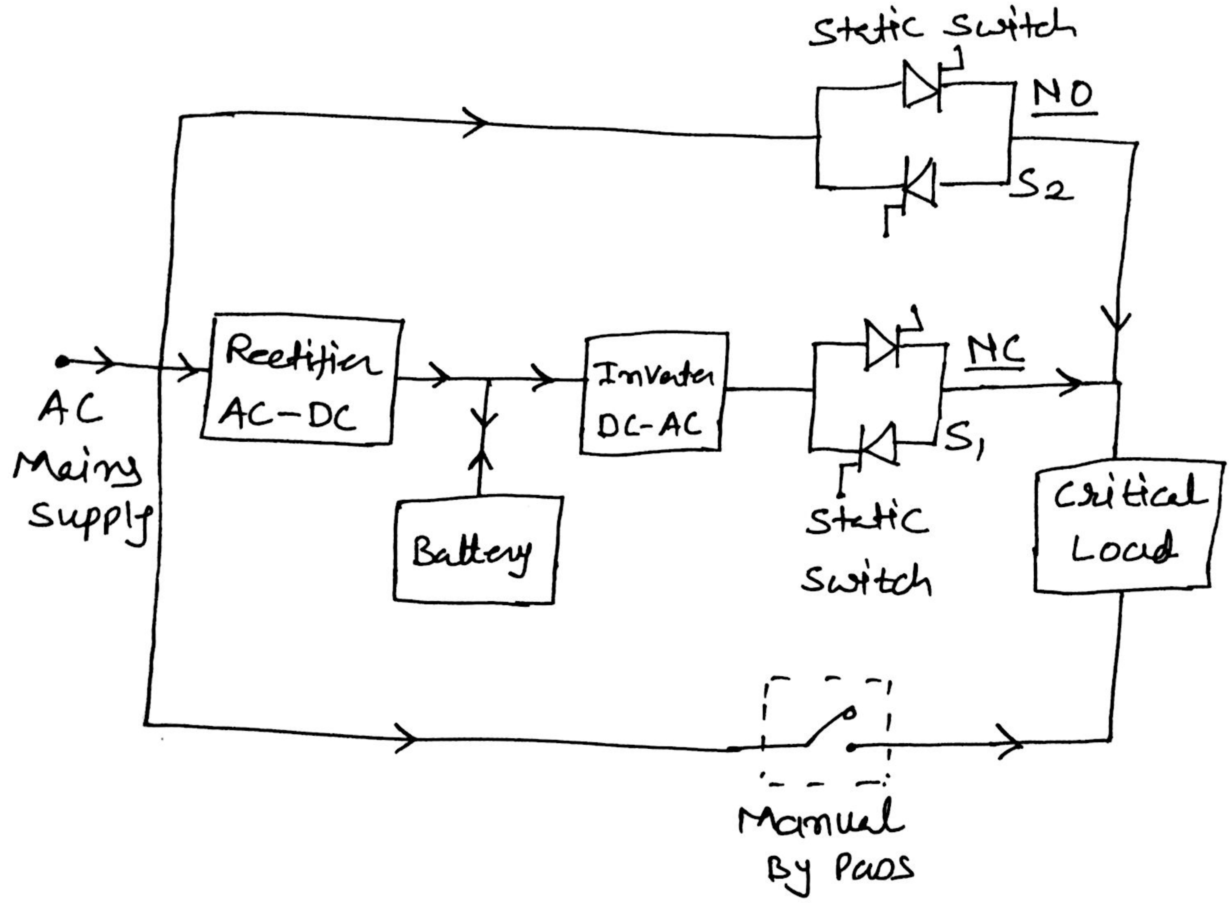
- The critical load connected to a UPS is normally supplied from AC mains supply.
- When AC mains fails the critical load is transfered to a inverter which is supplied by a charged battery system.
- The inverter then takes over the mains supply.
- The transfering of load from AC mains to inverter is done by a transfer switch.
- The transfer switch is a solid state switch which usually takes 4 to 5 ms for transfering the load.

Types of UPS

- OFF-Line UPS
- Line interactive UPS
- On-Line UPS

OFF-Line UPS

↳ In OFF Line UPS, critical load is normally connected to AC mains supply.



Block diagram OFF-Line UPS

↳ OFF line UPS consists of controlled rectifier, Inverter, Battery, Battery charging ckt, two static switch and a manual by pass switch.

↳ when AC Main supply is available the critical load is supplied through static switch S_2 which is normally ON (NO).

↳ When main supply is not available switch S_2 is turned off and switch S_1 is ON.

↳ The critical supply is connected to the inverter output.

↳ The inverter is supplied by a battery.

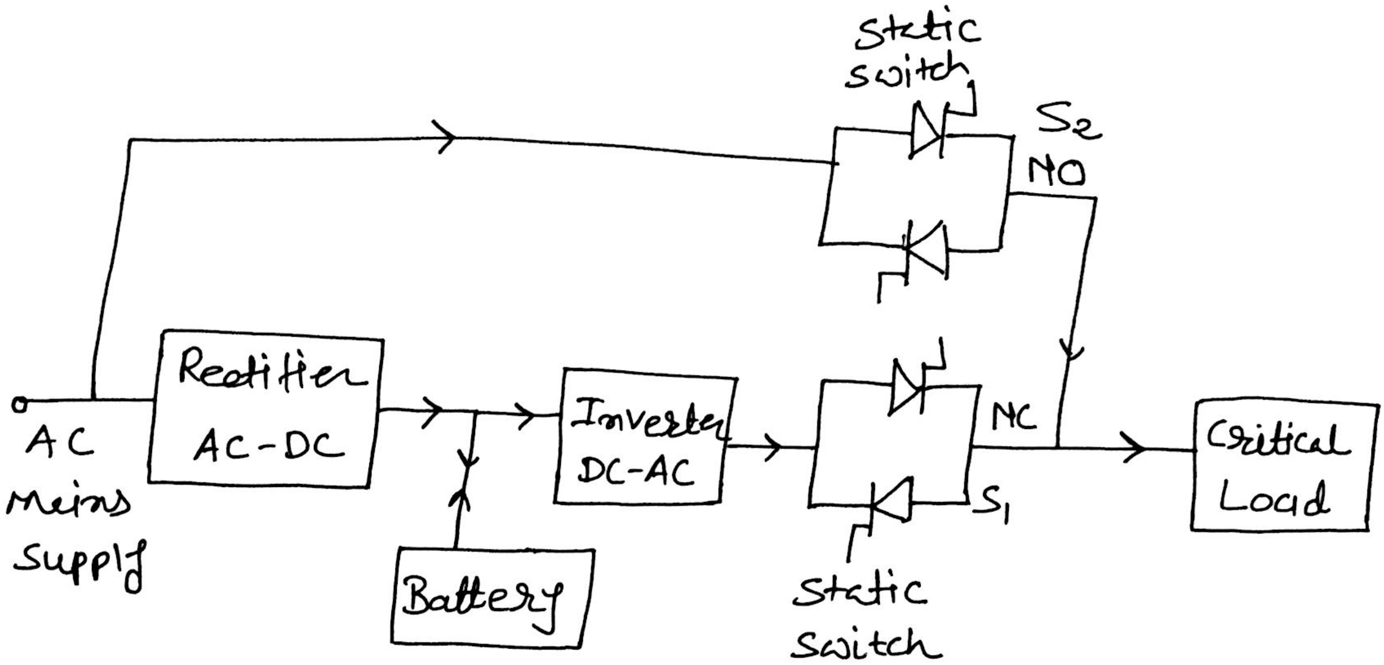
↳ During the period when AC main supply is available, battery is fully charged by a rectifier and a battery charger circuit.

↳ The static switch takes 4 to 5 ms of time to turn on & off, while mechanical contactor may take 30 to 50 ms of time for operation.

↳ Here in off line UPS the inverter runs only during the time when the supply failure occurs.

↳ During maintenance period manual bypass switch is used to supply the load when AC mains supply is available.

ON Line UPS



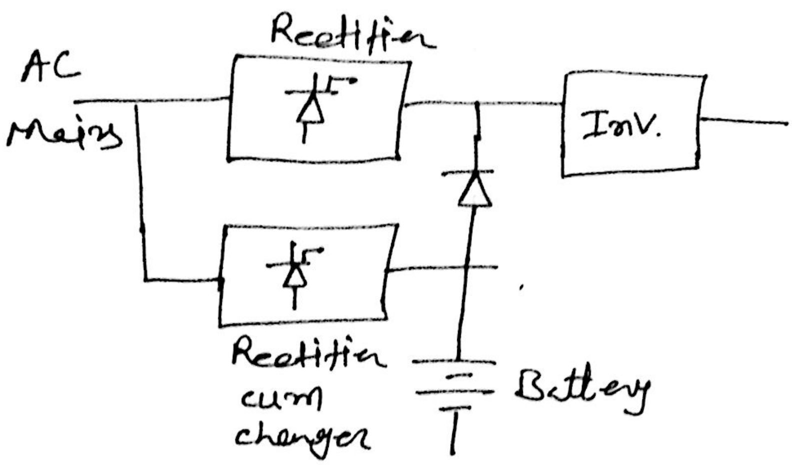
Block - Diagram of ON Line UPS

- The inverter in on-line UPS operates continuously wheather AC supply is avilable or not.
- The rectifire provides the necessary DC line voltage and charge the battery also.
- static switch S_1 is Normally close and S_2 is normally open.
- The inverter can be used to improve the power quality.
- The inverter can be used to protect the load from transients, voltage variation, frequency change.

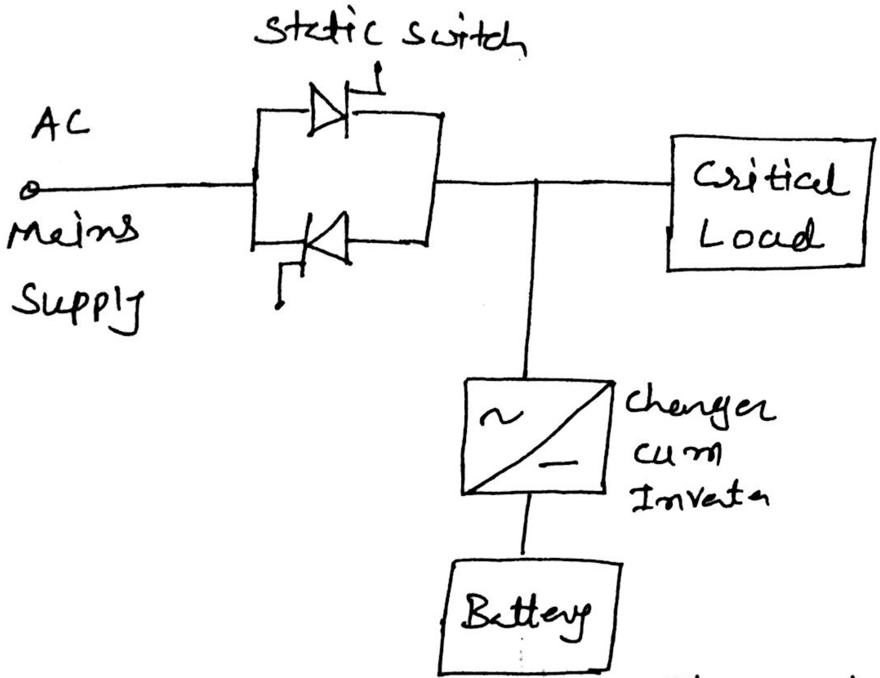
↳ The inverter is operated at fundamental output frequency with proper PWM scheme.

↳ There are some arrangements by which battery is isolated during main power is available.

↳ There may be SCR or Diode to control the battery power



Line Interactive UPS



Block Diagram of
Line interactive UPS

↳

↳ There is only one static switch provided in line interactive UPS.

↳ During the time AC mains supply is available critical load is supplied by AC mains.

↳ The Battery is charged with a charger cum inverter circuit.

↳ When the AC mains supply fails the battery supplies the inverter and supplies critical load.

↳ The static switch is off during this ~~top~~ time.

↳ The system is simple and economical.

↳ If some fault occurs in charger then the whole system fails.

↳ The output of inverter varies with load current and battery voltage.

↳

AC Power Supplies

Switched Mode AC Power supply

↳ The switched mode AC power supply consists of 3 stage conversion
↳ DC to AC, AC to DC and DC to AC.

↳ There are two inverters and a Buck converter.

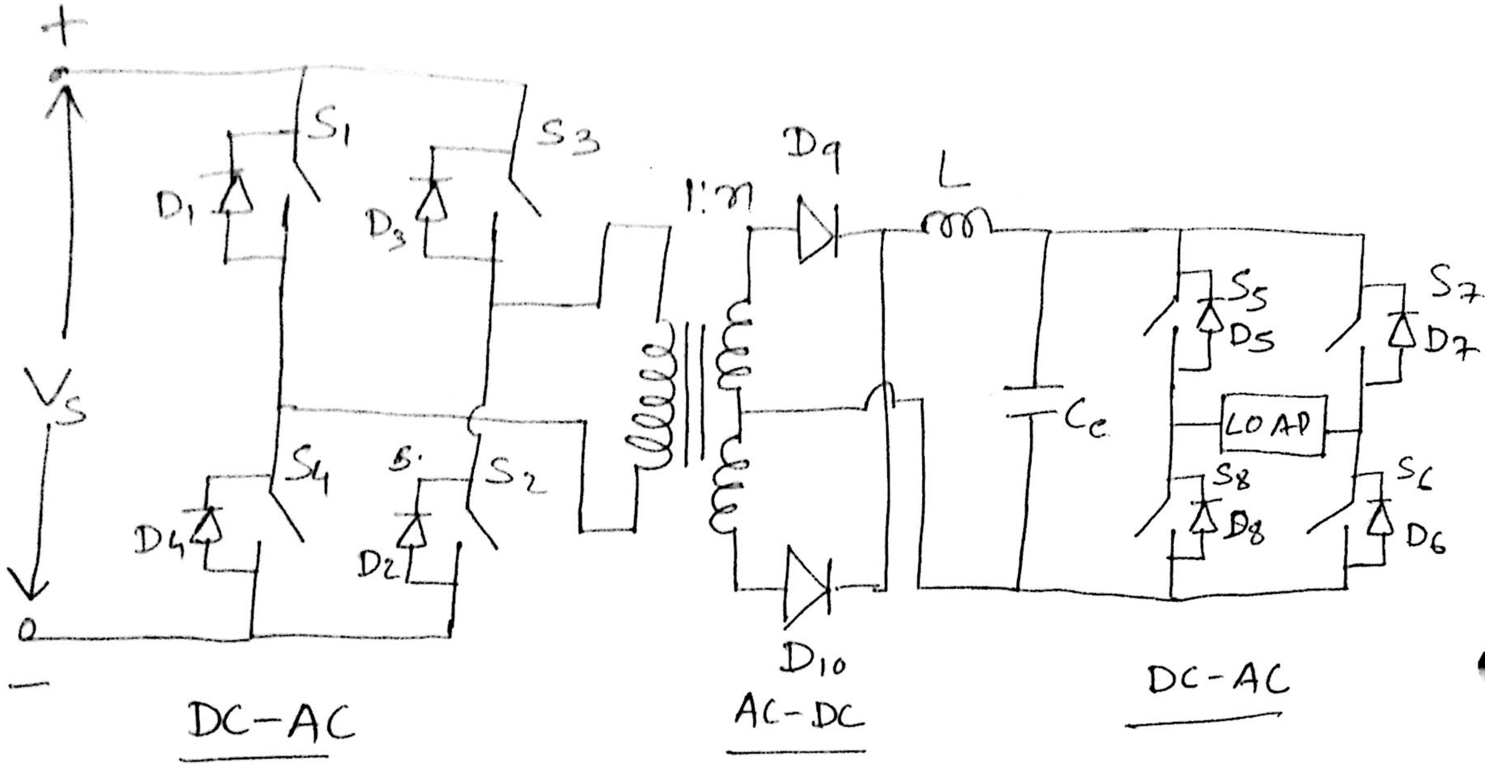
↳ The input side inverter operates with a PWM control at a very high frequency.

↳ By increasing the frequency of inverter, the size of the transformer reduces.

↳ Also the DC filter component at the input of outside filter reduces.

↳ Hence the size of ~~inverter~~ power supply reduces.

↳ The output side inverter operates at output frequency.



↳ As shown above