MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)

Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

Estd. 2000

L1

LECTURE HANDOUTS

EEE **III / V**

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit I : Power Semiconductor Devices **Date of Lecture:**

Topic of Lecture:

Introduction to Power Electronics

Introduction :

- The control of electric motor drives requires control of electric power.
- Power electronics have eased the concept of power control.
- Power electronics signifies the word power electronics and control or we can say the electronic that deal with power equipment for power control.

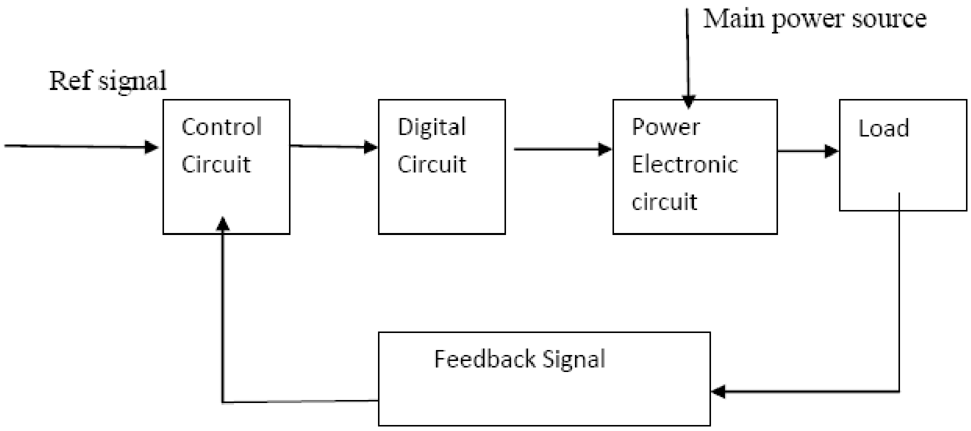
Prerequisite knowledge for Complete understanding and learning of Topic:

- Control circuit
- Feedback signal

Introduction to Power Electronics

- ✓ Power electronics is the applications of solid-state electronics for the control and conversion of electric power. Power electronic converters - to modify the form of electrical energy (voltage, current or frequency).
- ✓ Power range - from some milliwatts (mobile phone) to hundreds of megawatts (HVDC transmission system). With "classical" electronics, electrical currents and voltage are used to carry information, whereas with power electronics, they carry power. Thus, the main metric of power electronics becomes the efficiency.
- ✓ The first very high power electronic devices were mercury arc valves. In modern systems the conversion is performed with semiconductor switching devices such as diodes, thyristors and transistors. In contrast to electronic systems concerned with transmission and processing of signals and data, in power electronics substantial amounts of electrical energy are processed.
- ✓ An AC/DC converter (rectifier) is the most typical power electronics device found in many consumer electronic devices, e.g., television sets, personal computers, battery chargers, etc. The power range is typically from tens of watts to several hundred watts. In industrythe most common application is the variable speed drive (VSD) that is used to control aninduction motor. The power range of VSDs start from a few hundred watts and end at tens of megawatts.

- ✓ The power conversion systems can be classified according to the type of the input and output power
  - AC to DC (rectification)
  - DC to AC (inversion)
  - DC to DC (chopping)
  - AC to AC (transformation)
- ✓ Power electronics based on the switching of power semiconductor devices. With the development of power semiconductor technology, the power handling capabilities and switching speed of power devices have been improved tremendously.



- ✓ Power Semiconductor Devices The first SCR was developed in late 1957. Power semiconductor devices are broadly categorized into 3 types: 1. Power diodes (600V,4500A) 2. Transistors 3. Thyristors (10KV,300A,30MW)
- ✓ Some common power devices are the power diode, thyristor, power MOSFET and IGBT(insulated gate bipolar transistor). A power diode or MOSFET operates on similar principles to its low-power counterpart, but is able to carry a larger amount of current and typically is able to support a larger reverse-bias voltage in the off-state.
- ✓ Structural changes are often made in power devices to accommodate the higher current density, higher power dissipation and/or higher reverse breakdown voltage. The vast majority of the discrete (i.e non integrated) power devices are built using a vertical structure, whereas small-signal devices employ a lateral structure. With the vertical structure, the current rating of the device is proportional to its area, and the voltage blocking capability is achieved in the height of the die. With this structure, one of the connections of the device is located on the bottom of the semiconductor

Video Content / Details of website for further learning (if any):

- http://www.vssut.ac.in/lecture_notes/lecture1424354515.pdf
- https://www.youtube.com/watch?v=1Auay7ja2oY

Important Books/Journals for further learning including the page nos.: 04-09

P.S.Bimbra "Power Electronics" Khanna Publishers, third Edition, 2003.

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LECTURE HANDOUTS

L2

EEE

III / V

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit I : Power Semiconductor Devices **Date of Lecture:**

Topic of Lecture:

VI switching characteristics of power diode

Introduction :

- A Power diode and thyristor devices are most important in different power electronic converter topologies. However, the main differences between them are that the latter is a controlled device when it is turned on. Power diode controlled by the input source, while thyristors required to conditions to be controlled; the input source and gate control signal.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Diode
- P layer & N layer

VI switching characteristics of power diode

✓ Power diodes are made of silicon p-n junction with two terminals, anode and cathode. Diode is forward biased when anode is made positive with respect to the cathode. Diode conducts fully when the diode voltage is more than the cut-in voltage (0.7 V for Si). Conducting diode will have a small voltage drop across it.

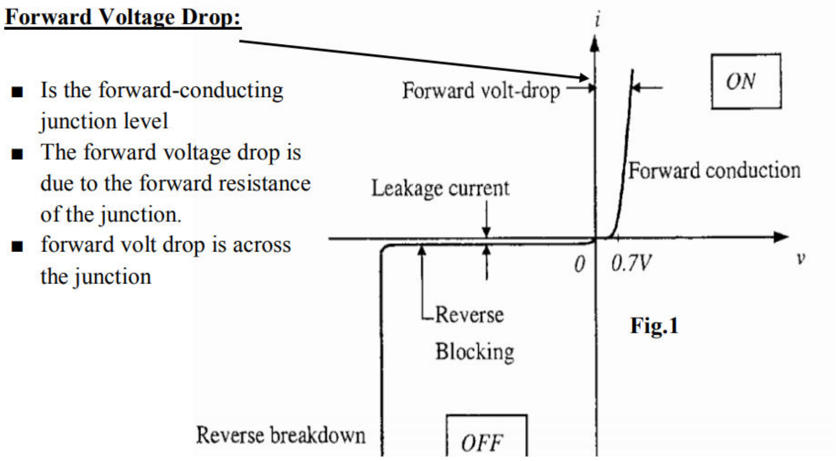


Fig.1

✓ Diode is reverse biased when cathode is made positive with respect to anode. When reverse biased, a small reverse current known as leakage current flows. This leakage current increases with increase in magnitude of reverse voltage until avalanche voltage is reached (breakdown voltage).

Reverse Recovery Characteristics

- ✓ When a diode is in forward conduction mode, a sudden reversal of the polarity of the applied voltage would not stop the diode current at once. But the diode continues to conduct in the opposite direction due to minority carriers that remain stored in pn-junction and the bulk semiconductor material. Figure shows the effect of minority carriers on the turn off characteristics of the power diode.

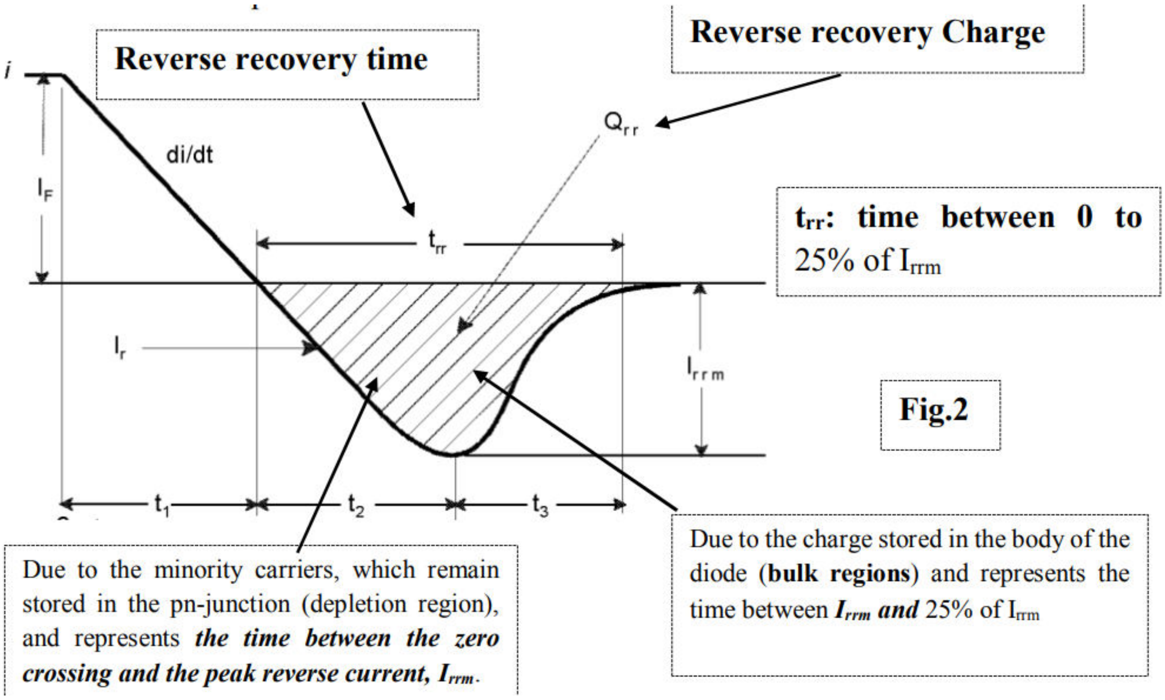


Fig.2

$$t_{rr} = t_2 + t_3 \quad I_{rr} = t_2 \frac{di}{dt} \quad \text{then} \quad Q_{rr} = \frac{1}{2} I_{rrm} t_2 + \frac{1}{2} I_{rrm} t_3 = \frac{1}{2} I_{rrm} t_{rr}$$

$$I_{rrm} \cong \frac{2Q_{rr}}{t_{rr}} = t_2 \frac{di}{dt}$$

For Fast recovery $t_3 \ll t_2 \rightarrow t_2 = t_{rr} \rightarrow t_{rr} = \sqrt{\frac{2Q_{rr}}{\frac{di}{dt}}}$

Hence, $I_{rrm} = \sqrt{2Q_{rr} \frac{di}{dt}}$

Video Content / Details of website for further learning (if any):

- https://odayahmeduot.files.wordpress.com/2015/11/lecture-03.pdf
- https://www.youtube.com/watch?v=zZo3JWyw_eo

Important Books/Journals for further learning including the page nos.: 10-15

P.S.Bimbra “Power Electronics” Khanna Publishers, third Edition, 2003.

Course Faculty

LECTURE HANDOUTS | **L3**

EEE | **III / V**

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit I : Power Semiconductor Devices **Date of Lecture:**

Topic of Lecture:

SCR - Silicon Controlled Rectifier

Introduction :

- Thyristor is a four layer three junction PNPN semiconductor switching device. It has 3 terminals these are anode, cathode and gate. SCRs are solid state device, so they are compact, possess high reliability and have low loss.

Prerequisite knowledge for Complete understanding and learning of Topic:

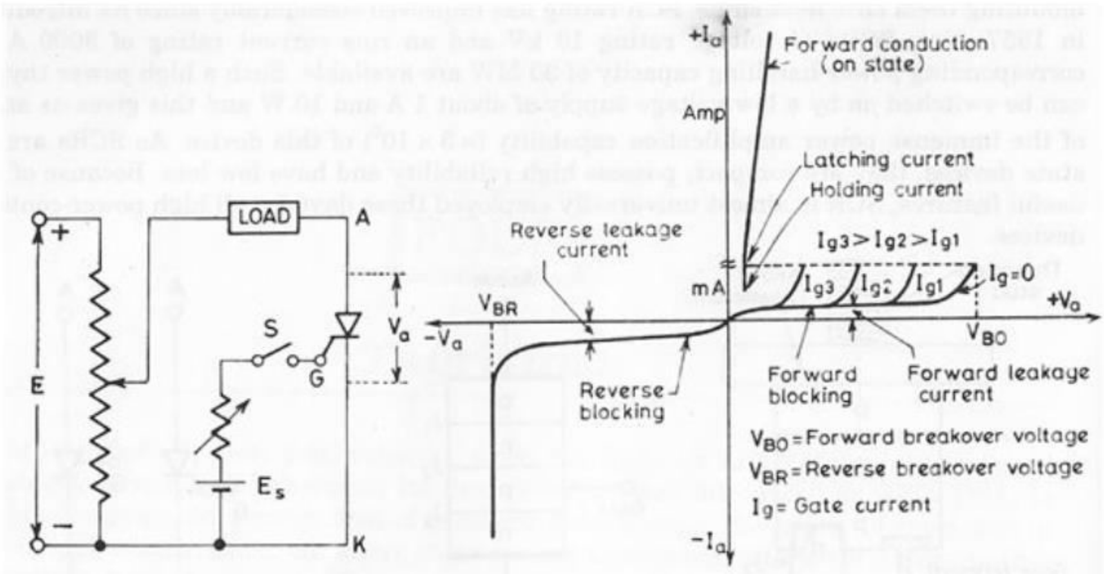
- Controlled and uncontrolled rectifier, Breakdown voltage & Biasing

V-I characteristic of SCR

- ✓ SCR have 3 modes of operation: 1. Reverse blocking mode 2. Forward blocking mode (off state) 3. Forward conduction mode (on state)

  1. Reverse Blocking Mode - When cathode of the thyristor is made positive with respect to anode with switch open thyristor is reverse biased. Junctions J1 and j2 are reverse biased where junction J2 is forward biased. The device behaves as if two diodes are connected in series with reverse voltage applied across them.
- ✓ A small leakage current of the order of few mA only flows. As the thyristor is• reverse biased and in blocking mode. It is called as acting in reverse blocking mode of operation. Now if the reverse voltage is increased, at a critical breakdown level called• reverse breakdown voltage Vrr, an avalanche occurs at J1 and J3 and the reverse current increases rapidly. As a large current associated with Vrr and hence more losses to the SCR.
- ✓ **2. Forward Blocking Mode** - When anode is positive with respect to cathode, with gate circuit open, thyristor is said to be forward biased. Thus junction J1 and J3 are forward biased and J2 is reverse biased. As the forward voltage is increases junction J2 will have an avalanche breakdown at a voltage called forward breakover voltage VBO. When forward voltage is less then VBO thyristor offers high impedance. Thus a thyristor acts as an open switch in forward blocking mode.
- ✓ **3. Forward Conduction Mode -** Thyristor conducts current from anode to cathode with a very small voltage drop across it. So a thyristor can be brought from forward blocking mode to forward conducting mode:
  a. By exceeding the forward break over voltage.

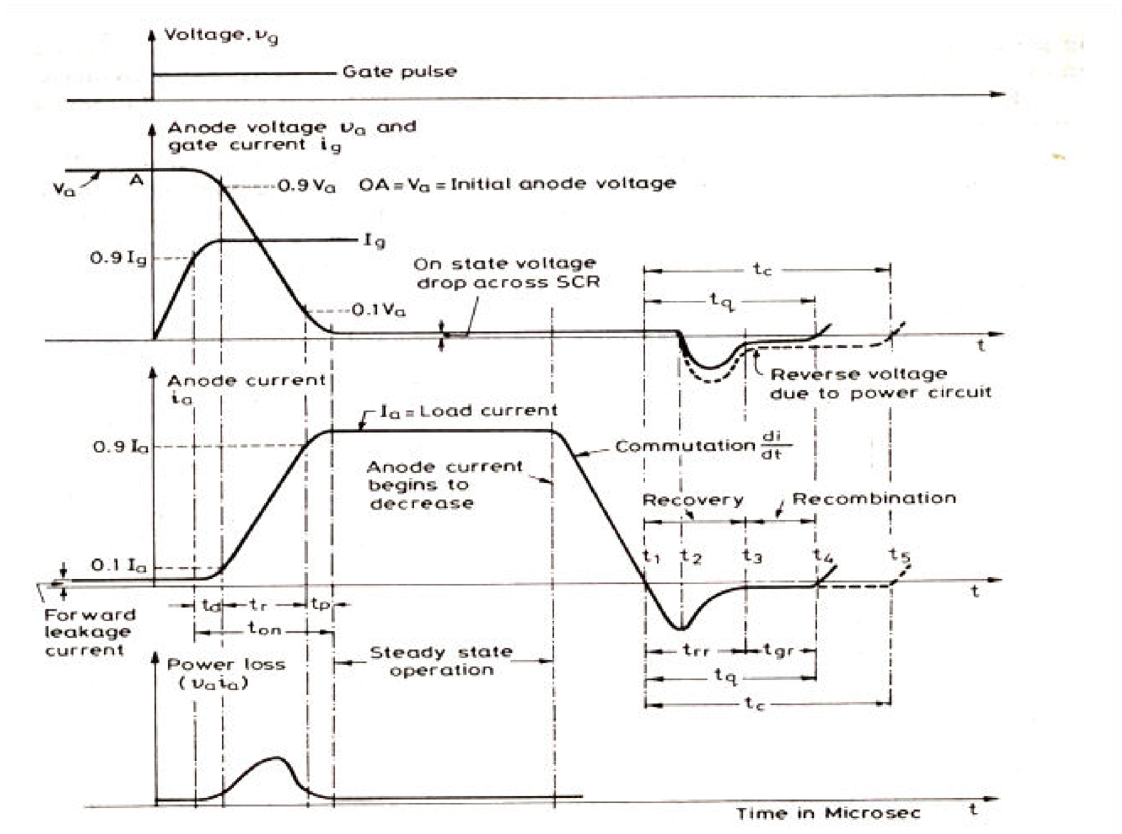
b. By applying a gate pulse between gate and cathode.



- ✓ The time variation of voltage across the thyristor and current through it during turn on and turn off process gives the dynamic or switching characteristic of SCR.

Switching characteristic

- ✓ Switching characteristic during turn on Turn on time It is the time during which it changes from forward blocking state to ON state. Total turn on time is divided into 3 intervals: 1. Delay time 2. Rise time 3. Spread time



Video Content / Details of website for further learning (if any):

- https://www.brighthubengineering.com/commercial-electrical-applications/58051-characteristics-and-applications-of-scr-thyristors/

Important Books/Journals for further learning including the page nos.: 18-21

P.S.Bimbra "Power Electronics" Khanna Publishers, third Edition, 2003.

Course Faculty

L4

LECTURE HANDOUTS

EEE | **III / V**

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit I : Power Semiconductor Devices **Date of Lecture:**

Topic of Lecture:

BJT – Bipolar Junction Transistor

Introduction :

- A bipolar junction transistor (bipolar transistor or BJT) is a type of transistor that uses both electrons and holes as charge carriers.
- Unipolar transistors, such as field-effect transistors, use only one kind of charge carrier. BJTs use two junctions between two semiconductor types, n-type and p-type.

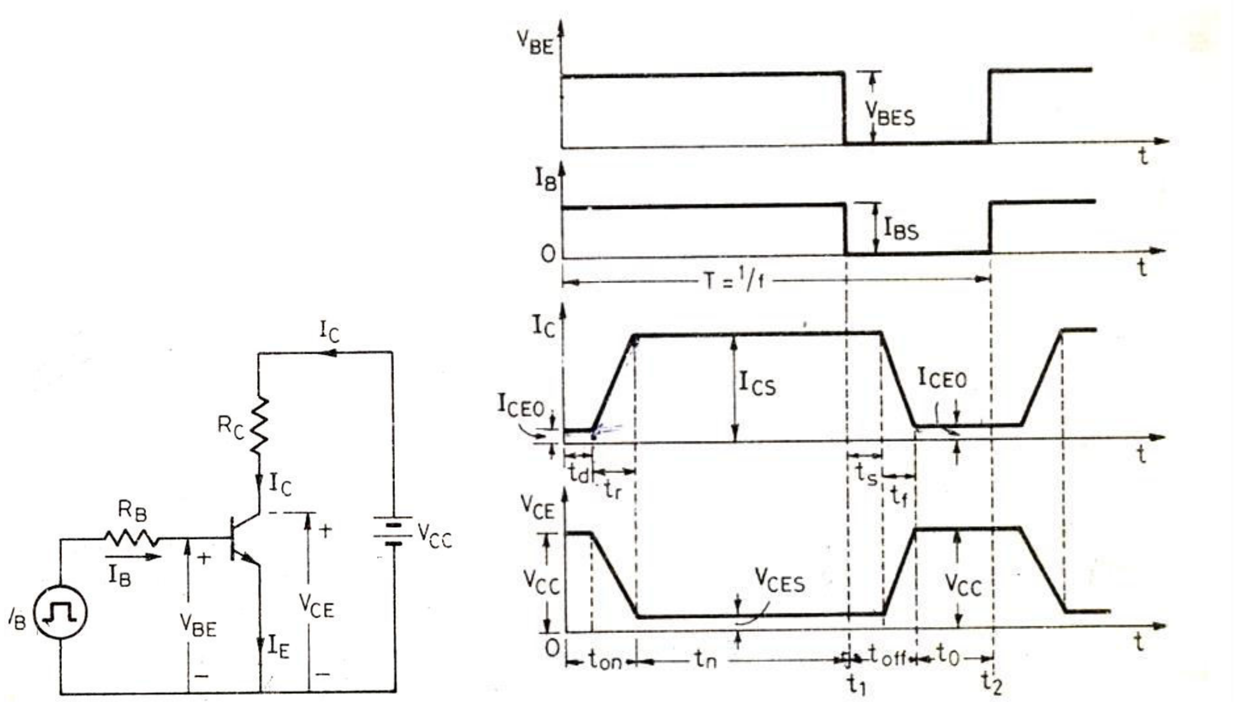
Prerequisite knowledge for Complete understanding and learning of Topic:

- Biasing and Breakdown voltage
- Bipolar Vs Unipolar

Bipolar Junction Transistor switching Characteristics

- ✓ The maxium collector emitter voltage that can be sustained across the junction, when it is carrying substantial collector current. Vceo = maxium collector and emitter voltage that can be sustain by the device. Vcbo=collector base breakdown voltage with emitter open
- ✓ **PRIMARY BREAKDOWN -** It is due to convention avalanche breakdown of the C-B junction and its associated large flow of current. The thickness of the depletion region determines the breakdown voltage of the transistor. The base thickness is made as small as possible, in order to have good amplification capability. If the thickness is too small, the breakdown voltage is compromised. So a compromise has to be made between the two.
- ✓ **SECONDARY BREAKDOWN -** Secondary breakdown is due to large power disspation at localized site within the semi conductor.
- ✓ PHYSICS **OF BJT OPERATION -** The transistor is assumed to operate in active region. There is no doped collector drift region. It has importance only in switching operation, in active region of operation. B-E junction is forward biased and C-B junction is reverse biased. Electrons are injected into base from the emitter. Holes are injected from base into the emitter.
- ✓ **QUASI SATURATION -** Initially we assume that, the transistor is in active region. Base current is allowed to increase then lets see what happens. first collector rises in response to base current. So there is a increase voltage drop across the collector load. So C-E voltage drops. Because of increase in collector current, there is a increase in voltage in drift region. This eventually reduces the reverse biased across the C-B junction.

- ✓ So n-p junction get smaller, at some point the junction become forward bised. So now injection of holes from base into collector drift region occurs. Charge neutrality requires the electron to be injected in the drift region of the holes. From where these electron came. Since a large no of electron is supplied to the C-B junction via injection from emitter and subsequent diffusion across the base. As excess carrier build up in the drift region begins to occur quasi saturation region is entered.
- ✓ As the injected carriers increase in the drift region is gradually shorted out and the voltage across the drift region drops. In quasi saturation the drift region is not completely shorted out by high level injection. Hard saturation obtained when excess carrier density reaches the n+ side. During quasi saturation, the rate of the collector falls. Hard saturation occurs when excess carriers have completely swept across the drift region.



Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=vJgW79mMRAU&vl=en
- https://www.electrical4u.com/bipolar-junction-transistor-or-bjt-n-p-n-or-p-n-p-transistor/

Important Books/Journals for further learning including the page nos.: 22-25

P.S.Bimbra "Power Electronics" Khanna Publishers, third Edition, 2003.

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LECTURE HANDOUTS

EEE | **III / V**

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit I : Power Semiconductor Devices **Date of Lecture:**

Topic of Lecture:

MOSFET – Metal Oxide Semiconductor Filed Effect Transistor

Introduction :

A power MOSFET has three terminal devices. Arrow indicates the direction of current flow. MOSFET is a voltage controlled device. The operation of MOSFET depends on flow of majority carriers only.

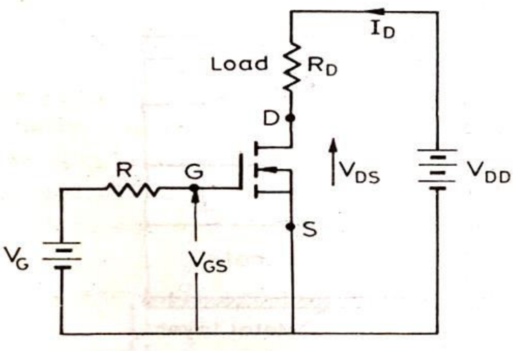
Prerequisite knowledge for Complete understanding and learning of Topic:

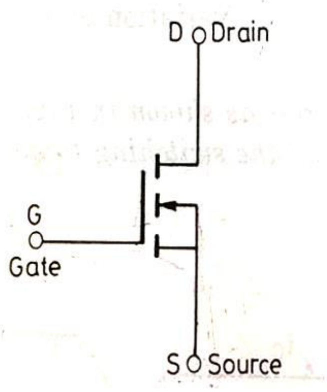
- BJT operation
- Biasing and Breakdown voltage

MOSFET operating regions

In general, any MOSFET is seen to exhibit three operating regions viz.,

- ✓ Cut-Off Region – it is a region in which the MOSFET will be OFF as there will be no current flow through it. In this region, MOSFET behaves like an open switch and is thus used when they are required to function as electronic switches.
- ✓ Ohmic or Linear Region – it is a region where in the current IDS increases with an increase in the value of VDS. When MOSFETs are made to operate in this region, they can be used as amplifiers.

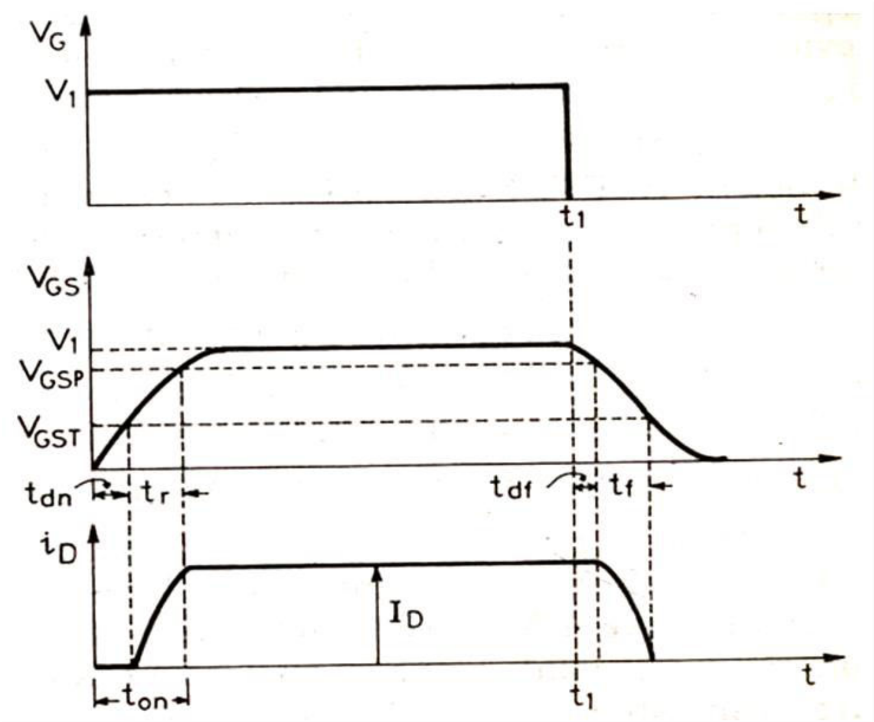




- ✓ Saturation Region - The MOSFETs have their IDS constant inspite of an increase in VDS and occurs once VDS exceeds the value of pinch-off voltage VP. Under this condition, the device will act like a closed switch through which a saturated value of IDS flows. As a result, this operating region is chosen whenever MOSFETs are required to perform switching operations.

Switching Characteristics:-

- ✓ The switching characteristic is influenced by 1. Internal capacitance of the device. 2. Internal impedance of the gate drive circuit.
- ✓ **Total turn on time** is divided into 1.Turn on delay time 2.Rise time
- ✓ Turn on time is affected by impedance of gate drive source. During turn on delay time gate to source voltage attends its threshold value $VGST$. After tdn and during rise time gate to source voltage rise to $VGsp$, a voltage which is sufficient to drive the MOSFET to ON state. The turn off process is initiated by removing the gate to source voltage. Turn off time is composed of turn off delay time to fall time.
- ✓ **Turn off delay time -** To turn off the MOSFET the input capacitance has to be discharged During tdf the input capacitance discharge from $V1$to $VGsp$. During tf, fall time, the input capacitance discharges from $VGsp$ to $VGST$. During tf drain current falls from ID to zero.
- ✓ So when $VGs \leq VG$, MOFSET turn off is complete.



Video Content / Details of website for further learning (if any):

- http://www.vssut.ac.in/lecture_notes/lecture1424354515.pdf
- https://www.youtube.com/watch?v=ULbcAYR_SOk

Important Books/Journals for further learning including the page nos.: 26-29

P.S.Bimbra "Power Electronics" Khanna Publishers, third Edition, 2003

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L6

LECTURE HANDOUTS

EEE **III / V**

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit I : Power Semiconductor Devices **Date of Lecture:**

Topic of Lecture:

Insulated Gate Bipolar Transistor (IGBT)

Introduction :

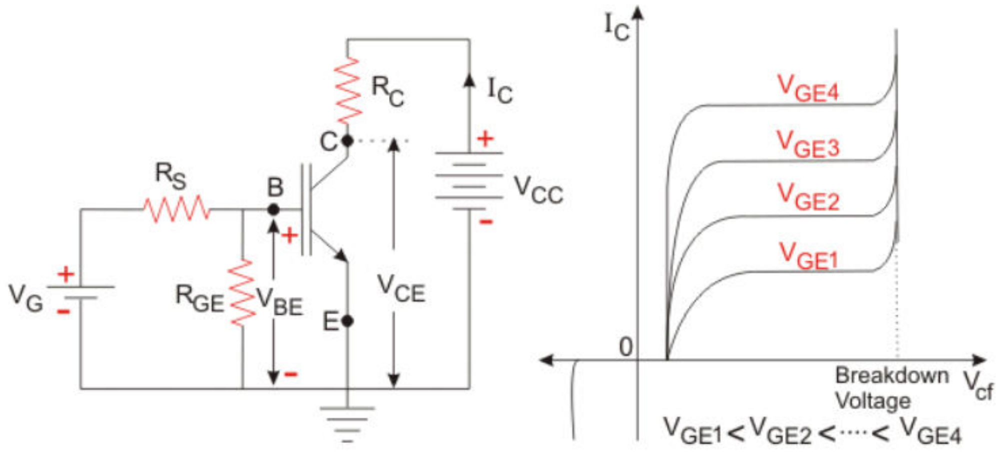
- IGBT is a relatively new device in power electronics and before the advent of IGBT, Power MOSFETs and Power BJT were common in use in power electronic applications.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Operation of BJT & MOSFET
- Two transistor analogy

VI characteristics of IGBT

✓ The figure below shows static VI characteristics of an n-channel IGBT along with a circuit diagram with the parameters marked.

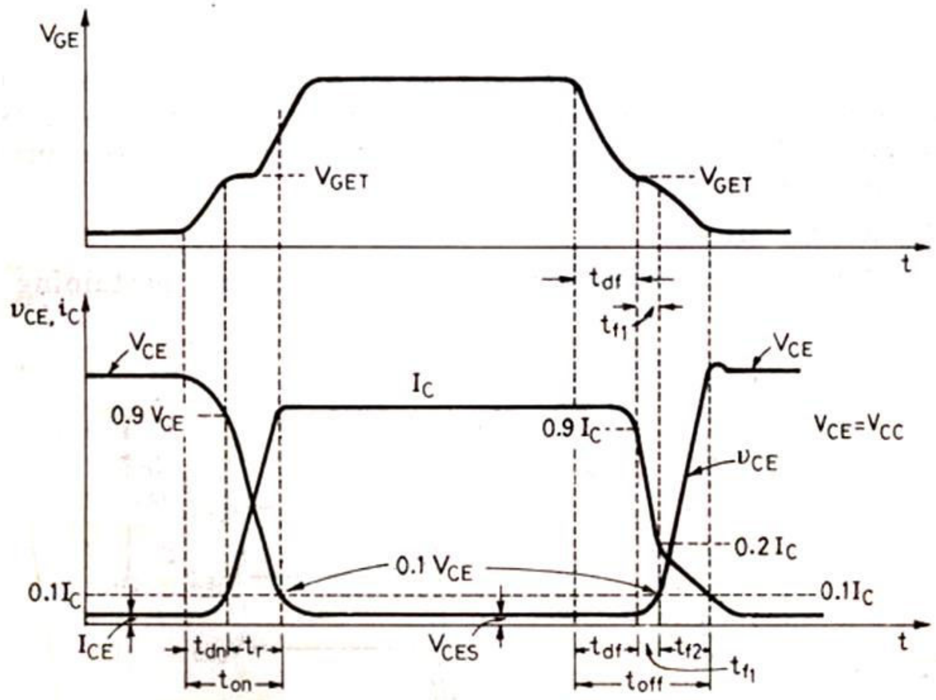


Circuit Diagram　　Static I - V Characteristics

✓ The graph is similar to that of a BJT except that the parameter which is kept constant for a plot is VGE because IGBT is a voltage controlled device unlike BJT which is a current controlled device. When the device is in OFF mode (VCE is positive and VGE < VGET) the reverse voltage is blocked by J2 and when it is reverse biased, i.e. VCE is negative, J1 blocks the voltage.

Switching characteristics:

- ✓ Switching characteristics: Figure below shows the turn ON and turn OFF characteristics of IGBT
- ✓ Turn on time Time between the instants forward blocking state to forward on state.
  Turn on time = Delay time + Rise time
  Delay time = Time for collector emitter voltage fall from VCE to 0.9VCE, VCE=Initial collector emitter voltage, tdn=collector current to rise from initial leakage current to 0.1Ic, Ic= Final value of collector current



- ✓ Rise time Collector emitter voltage to fall from 0.9VCE to 0.1VCE. 0.1Ic to Ic After ton the device is on state the device carries a steady current of Ic and the collector emitter voltage falls to a small value called conduction drop $VCES$.
- ✓ Turn off time 1) Delay time tdf 2) Initial fall time tf1 3) Final fall time tf2
  $tOff$ =tdf + tf1+ tf2
- ✓ tdf = Time during which the gate emitter voltage falls to the threshold value $VGET$. Collector current falls from Ic to 0.9Ic at the end of the tdf collector emitter voltage begins to rise.
- ✓ Turn off time = Collector current falls from 90% to 20% of its initial value Ic OR The time during which collector emitter voltage rise from VCE to 0.1VCE, tf2 = collector current falls from20% to 10% of Ic. During this collector emitter voltage rise 0.1VCE to final value of VCE.

Video Content / Details of website for further learning (if any):

- https://www.electrical4u.com/insulated-gate-bipolar-transistor-igbt/
- https://www.youtube.com/watch?v=ULbcAYR_SOk

Important Books/Journals for further learning including the page nos.: 30-33

P.S.Bimbra “Power Electronics” Khanna Publishers, third Edition, 2003.

Course Faculty

L7

LECTURE HANDOUTS

EEE

III / V

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit I : Power Semiconductor Devices **Date of Lecture:**

Topic of Lecture:

SCR two transistor analogy

Introduction :

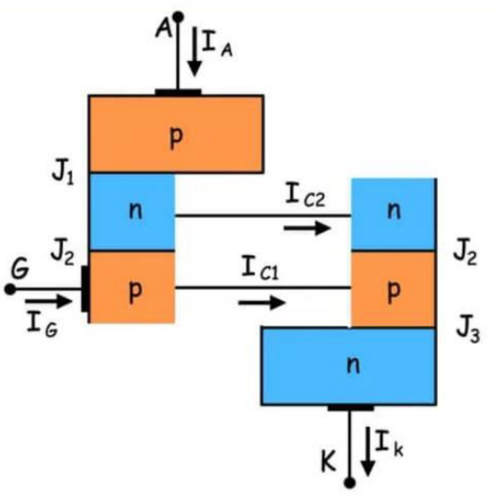
- Although the thyristor is extensively used in high power applications, it always suffered from being a semi-controlled device. Even though it could be switched ON by applying a gate signal, it has to be turned OFF by interrupting the main current using a commutation circuit.

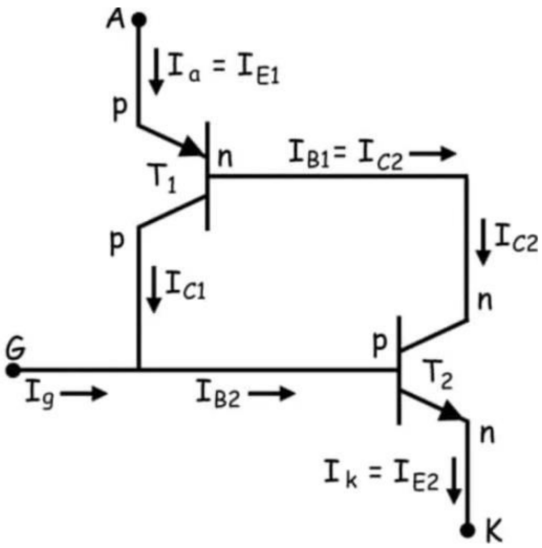
Prerequisite knowledge for Complete understanding and learning of Topic:

- Thyristor / SCR
- Bipolar

SCR two transistor analogy

- ✓ Basic operating principle of SCR, can easily be understood by the **two transistor model of SCR**, as it is a combination of p and n layers.
- ✓ This is a pnpn thyristor. If we bisect it through the dotted line then we will get two transistors i.e. one pnp transistor with J_1 and J_2 junctions and another is with J_2 and J_3 junctions as shown in figure below.





Where, I_B is base current and β is common emitter forward current gain.

Let's for transistor T_1 this relation holds

$$I_{C1} = \alpha_1 I_a + I_{CBO1} \ldots\ldots (i)$$

And that for transistor T_2

$$I_{C2} = \alpha_2 I_k + I_{CBO2} \ldots\ldots (ii) \ again \ I_{C2} = \beta_2 I_{B2}$$

Now, by the analysis of two transistors model we can get anode current,

$$I_a = I_{C1} + I_{C2} \ [applying \ KCL]$$

From equation (i) and (ii), we get,

$$I_a = \alpha_1 I_a + I_{CBO1} + \alpha_2 I_k + I_{CBO2} \ldots\ldots (iii)$$

If applied gate current is I_g then cathode current will be the summation of anode current and gate current i.e.

$$I_k = I_a + I_g$$

✓

By substituting this valyue of I_k in (iii) we get,

$$I_a = \alpha_1 I_a + I_{CBO1} + \alpha_2 (I_a + I_g) + I_{CBO2}$$

$$I_a = \frac{\alpha_2 I_g + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)}$$

From this relation we can assure that with increasing the value of
$(\alpha_1 + \alpha_2)$
towards unity, corresponding anode current will increase. Now the question is how
$(\alpha_1 + \alpha_2)$
increasing? Here is the explanation using **two transistor model of SCR**.

At the first stage when we apply a gate current I_g, it acts as base current of T_2 transistor i.e. $I_{B2} = I_g$ and emitter current of the T_2 transistor $I_{E2} = I_k$. Hence establishment of the emitter current gives rise α_2 as

$$\alpha_2 = \frac{I_{CBO1}}{I_g}$$

Presence of base current will generate collector current as

$$I_{C2} = \beta_2 \times I_{B2} = \beta_2 I_g$$

Video Content / Details of website for further learning (if any):

- https://www.electronicshub.org/wp-content/uploads/2015/05/GTO-Symbols.jpg
- https://www.polytechnichub.com/v-characteristic-gto-gate-turn-off-thyristor/

Important Books/Journals for further learning including the page nos.: 38-42

P.S.Bimbra "Power Electronics" Khanna Publishers, third Edition, 2003.

Course Faculty

L8

LECTURE HANDOUTS

EEE

III / V

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit I : Power Semiconductor Devices **Date of Lecture:**

Topic of Lecture:

Snubber Protection Circuits

Introduction :

- For satisfactory and reliable operation, the specified ratings of an SCR should not be exceeded due to overload, voltage transients and other abnormal conditions. If the ratings are exceeded, there is a chance of damage permanently to the SCR. Due to the reverse recovery process during the turn OFF the SCR, the voltage overshoots occur in the SCR.

Prerequisite knowledge for Complete understanding and learning of Topic:

- SCR operation
- L & C components property

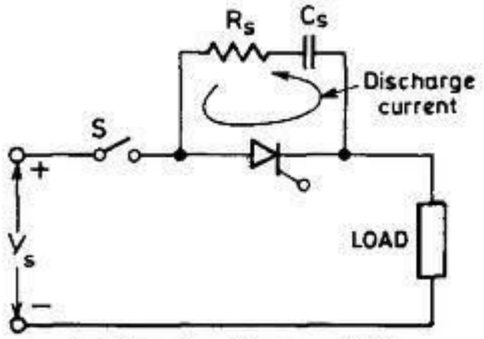
Snubber Protection Circuits

- ✓ Overvoltage - Over voltages are the greatest causes of failure of SCRs. These transient over voltages often lead to unscheduled turn ON of the SCR. Also, may lead to the permanent destruction of the SCR if the reverse transient voltage is more than the VBR across the SCR.

- ✓ Internal Overvoltage's - Internal over voltages arise while the SCR is in operation. During the turn OFF of an SCR, a reverse current continues to flow through the SCR after the anode current decreased to zero to sweep away the earlier stored charge. This reverse current decay at a faster rate at the end of reverse recover interval. Due to the inductance of the circuit, this high di/dt produces a high voltage. This voltage value may be much higher than the rated value of the SCR and hence the SCR may be damaged.

- ✓ External Overvoltage's - These voltages are arises from the supply source or load. Some of these are If SCRs are in blocking mode in a converter circuit which is supplied with transformer, a small magnetizing current flow through the primary of the transformer. If the primary side switch is suddenly removed, a high voltage transient is produced in the secondary of the transformer and hence it is applied across the SCR. This voltage is several times that of the

- ✓ Lightning surges on the HVDC systems to which SCR converters are connected causes a very high magnitude of over voltages.
- ✓ If the SCR converter circuit is connected to a high inductive load, the sudden interruption of current generates a high voltage across the SCRs.
- ✓ If the switches are provided on DC side, a sudden operation of these switches produces arc voltages. This also gives rise the over voltage across the SCR.



Snubber circuit across SCR.

- ✓ Protection Against Over voltages - To protect the SCR against the transient over voltages, a parallel R-C snubber network is provided for each SCR in a converter circuit. This snubber network protects the SCR against internal over voltages that are caused during the reverse recovery process. After the SCR is turned OFF or commutated, the reverse recover current is diverted to the snubber circuit which consists of energy storing elements.
- ✓ The lightning and switching surges at the input side may damage the converter or the transformer. And the effect of these voltages is minimised by using voltage clamping devices across the SCR. Therefore, voltage clamping devices like metal oxide varistors, selenium thyrector diodes and avalanche diode suppressors are most commonly employed.
- ✓ Overcurrent - During the short circuit conditions, over current flows through the SCR. These short circuits are either internal or external. The internal short circuits are caused by the reasons like failure of SCRs to block forward or reverse voltages, misalignment of firing pulses, short circuit of converter output terminals due to fault in connecting cables or the load, etc. The external short circuits are caused by sustained overloads and short circuit in the load.
- ✓ Protection Against Overcurrent - The SCRs can be protected against the over currents using conventional over current protection devices like ordinary fuses (HRC fuse, rewirable fuse, semiconductor fuse, etc,), contractors, relays and circuit breakers. Generally for continuous overloads and surge currents of long duration, a circuit breaker is employed to protect the SCR due to its long tripping time.

Video Content / Details of website for further learning (if any):

- https://www.electronicshub.org/scr-protection/
- https://www.youtube.com/watch?v=rRzFgJvsbLI

Important Books/Journals for further learning including the page nos.: 56-59

P.S.Bimbra “Power Electronics” Khanna Publishers, third Edition, 2003.

Course Faculty

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit I : Power Semiconductor Devices **Date of Lecture:**

Topic of Lecture:

SCR Triggering and Commutation Circuits

Introduction : (Maximum 5 sentences)

- We know that the SCR has two stable states as forward blocking and forward conduction state. Switching the SCR from forward blocking state (OFF- state) to forward conduction state (ON-state) is known as turning ON process of SCR . It is also called as triggering.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Voltage control
- Triggering

Triggering methods

Triggering means turning ON of a device from its off state. Turning ON of a thyristor refers to thyristor triggering. Thyristor is turned on by increasing the anode current flowing through it. The increase in anode current can be achieved by many ways.

- ✓ **Voltage Thyristor Triggering**:- Here the applied forward voltage is gradually increased beyond a pt. known as forward break over voltage VBO and gate is kept open. This method is not preferred because during turn on of thyristor, it is associated with large voltage and large current which results in huge power loss and device may be damaged.
- ✓ **Thermal Thyristor Triggering**:- If the temperature of the thyristor is high, it results in increase in the electron-hole pairs. Which in turn increase the leakage current α1 and α2 to raise. The regenerative action tends to increase (α1 + α2) to units and the thyristor may be turned on. This type turn on is not preferred as it may result in thermal turn away and hence it is avoided.
- ✓ **Light Thyristor Triggering**:- These rays of light are allowed to strike the junctions of the thyristor. This result in an increase in the number of electron-hole pair and thyristor may be turned on. The light-activated SCRs (LASER) are triggered by using this method.
- ✓ **dv/dt Triggering**:- If the rate of rise of anode to cathode voltage is high, the charging current through the capacitive junction is high enough to turn on the thyristor. A high value of charging current may destroy the thyristor hence the device must be protected against high dv/dt.

- ✓ **Gate Triggering**:- This method of **thyristor triggering** is widely employed because of ease C8 control over the thyristor gate triggering of thyristor allows us to turn of the thyristor whenever we wish. Here we apply a gate signal to the thyristor. Forward biased thyristor will turn on when gate signal is applied to it. Once the thyristor starts conducting, the gate loses its control over the device and the thyristor continues to conduct. This is because of regenerative action that takes place within the thyristor when gate signal is applied.

Commutation techniques:

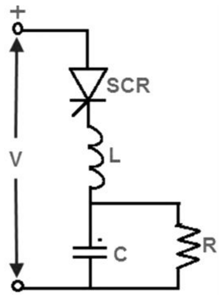
- ✓ Commutation techniques of thyristors are classified into two types:
  Natural Commutation
  Forced Commutation

Natural Commutation

- ✓ Generally, if we consider AC supply, the current will flow through the zero crossing line while going from positive peak to negative peak. Thus, a reverse voltage will appear across the device simultaneously, which will turn off the thyristor immediately. This process is called as natural commutation as thyristor is turned off naturally without using any external components or circuit or supply for commutation purpose.

Forced Commutation

- ✓ The thyristor can be turned off by reverse biasing the SCR or by using active or passive components. Thyristor current can be reduced to a value below the value of holding current. Since, the thyristor is turned off forcibly it is termed as a forced commutation process. The basic electronics and electrical components such as inductance and capacitance are used as commutating elements for commutation purpose.
- ✓ Forced commutation can be observed while using DC supply; hence it is also called as DC commutation. The external circuit used for forced commutation process is called as commutation circuit and the elements used in this circuit are called as commutating elements.



Video Content / Details of website for further learning (if any):

- https://www.electrical4u.com/thyristor-triggering/
- https://www.elprocus.com/classification-of-thyristor-commutation-methods/

Important Books/Journals for further learning including the page nos.: 50-55

P.S.Bimbra "Power Electronics" Khanna Publishers, third Edition, 2003.

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

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L10

LECTURE HANDOUTS

EEE **III / V**

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit II : AC - DC Converters **Date of Lecture:**

Topic of Lecture:

Principles of phase controlled converter and Performance parameters

Introduction :

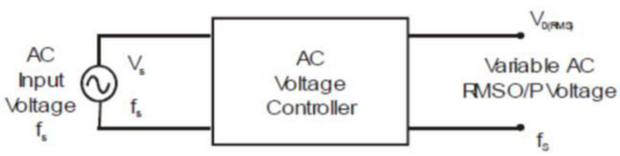
- The controlled rectifier is obtained by replacing the diodes of the uncontrolled rectifier with thyristors. Control over the output dc voltage is obtained by controlling the conduction interval of each thyristor. This method is known as phase control and converters are also called "phase controlled converters"

Prerequisite knowledge for Complete understanding and learning of Topic:

- Rectifier
- Triggering methods

Introduction to phase controlled converter

- ✓ AC voltage controllers (ac line voltage controllers) are employed to vary the RMS value of the alternating voltage applied to a load circuit by introducing Thyristors between the load and a constant voltage ac source. The RMS value of alternating voltage applied to a load circuit is controlled by controlling the triggering angle of the Thyristors in the ac voltage controller circuits.
- ✓ In brief, an ac voltage controller is a type of thyristor power converter which is used to convert a fixed voltage, fixed frequency ac input supply to obtain a variable voltage ac output. The RMS value of the ac output voltage and the ac power flow to the load is controlled by varying (adjusting) the trigger angle 'α



- ✓ There are two different types of thyristor control used in practice to control the ac power flow • On-Off control • Phase control. These are the two ac output voltage control techniques. In On-Off control technique Thyristors are used as switches to connect the load circuit to the ac supply (source) for a few cycles of the input ac supply and then to disconnect it for few input cycles. The Thyristors thus act as a high speed contactor (or high speed ac switch).

Phase Control converter

- ✓ In phase control the Thyristors are used as switches to connect the load circuit to the input ac supply, for a part of every input cycle. That is the ac supply voltage is chopped using Thyristors during a part of each input cycle. The thyristor switch is turned on for a part of every half cycle, so that input supply voltage appears across the load and then turned off during the remaining part of input half cycle to disconnect the ac supply from the load. By controlling the phase angle or the trigger angle ‘α’ (delay angle), the output RMS voltage across the load can be controlled.
- ✓ The trigger delay angle ‘α’ is defined as the phase angle (the value of ωt) at which the thyristor turns on and the load current begins to flow. Thyristor ac voltage controllers use ac line commutation or ac phase commutation. Thyristors in ac voltage controllers are line commutated (phase commutated) since the input supply is ac. When the input ac voltage reverses and becomes negative during the negative half cycle the current flowing through the conducting thyristor decreases and falls to zero. Thus the ON thyristor naturally turns off, when the device current falls to zero. Phase control Thyristors which are relatively inexpensive, converter grade
- ✓ Thyristors which are slower than fast switching inverter grade Thyristors are normally used. For applications upto 400Hz, if Triacs are available to meet the voltage and current ratings of a particular application, Triacs are more commonly used. Due to ac line commutation or natural commutation, there is no need of extra commutation circuitry or components and the circuits for ac voltage controllers are very simple. Due to the nature of the output waveforms, the analysis, derivations of expressions for performance parameters are not simple, especially for the phase controlled ac voltage controllers with RL load. But however most of the practical loads are of the RL type and hence RL load should be considered in the analysis and design of ac voltage controller circuits.

Type of Ac Voltage Controllers

- ✓ The ac voltage controllers are classified into two types based on the type of input ac supply applied to the circuit. • Single Phase AC Controllers. • Three Phase AC Controllers.
- ✓ In brief different types of ac voltage controllers are • Single phase half wave ac voltage controller (uni-directionalcontroller). • Single phase full wave ac voltage controller (bi-directional controller). • Three phase half wave ac voltage controller (uni-directionalcontroller). • Three phase full wave ac voltage controller (bi-directional controller).

Applications of Ac Voltage Controllers

- ✓ • Lighting / Illumination control in ac power circuits. • Induction heating. • Industrial heating & Domestic heating. • Transformer tap changing (on load transformer tap changing). • Speed control of induction motors (single phase and poly phase ac induction motor control). • AC magnet controls.

Video Content / Details of website for further learning (if any):

- http://www.gvpcew.ac.in/Material%203%20Units/3%20EEE%20PE.pdf
- https://www.youtube.com/watch?v=1eTKwOC-CZo

Important Books/Journals for further learning including the page nos.: 70-73

P.S.Bimbra “Power Electronics” Khanna Publishers, third Edition, 2003.

Course Faculty

LECTURE HANDOUTS

L11

EEE

III / V

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit II : AC - DC Converters **Date of Lecture:**

Topic of Lecture:

Single Phase Half controlled converter R and RL Load

Introduction :

- Rectification converts an oscillating sinusoidal AC voltage source into a constant current DC voltage supply by means of diodes, thyristors, transistors, or converters. This rectifying process can take on many forms with half-wave, full-wave, uncontrolled and fully-controlled rectifiers transforming a single-phase or three-phase supply into a constant DC level

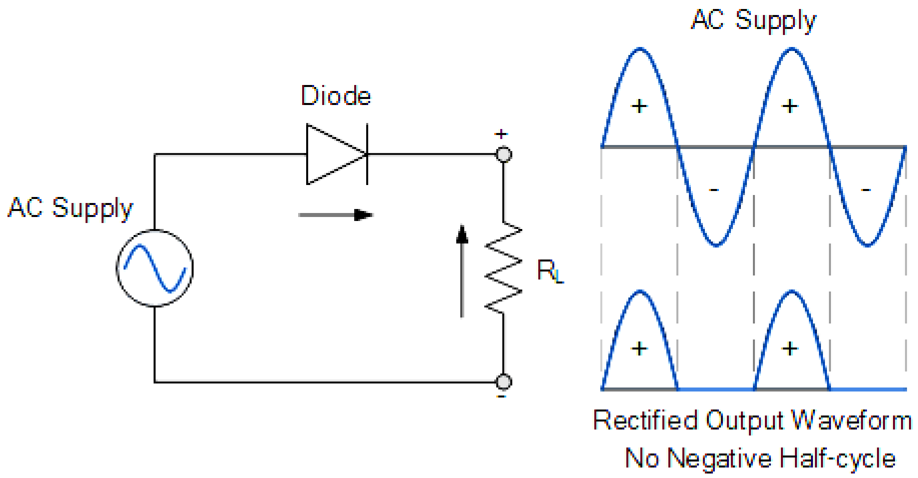
Prerequisite knowledge for Complete understanding and learning of Topic:

- Rectifier
- Switching devices

Single Phase Half controlled converter with R

✓ The single-phase half-wave rectifier configuration above passes the positive half of the AC supply waveform with the negative half being eliminated. By reversing the direction of the diode we can pass negative halves and eliminate the positive halves of the AC waveform. Therefore the output will be a series of positive or negative pulses.

✓ There is no voltage or current applied to the connected load, R for half of each cycle. In other words, the voltage across the load resistance, R consists of only half waveforms, either positive or negative, as it operates during only one-half of the input cycle, hence the name of half-wave rectifier.



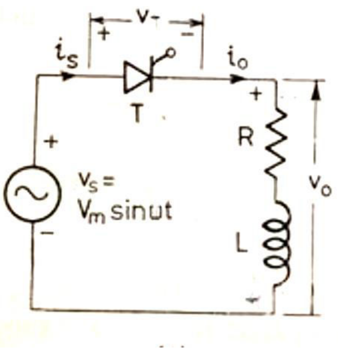
- ✓ Hopefully we can see that the diode allows current to flow in one direction only producing an output which consists of half-cycles. This pulsating output waveform not only varies ON and OFF every cycle, but is only present 50% of the time and with a purely resistive load, this high voltage and current ripple content is at its maximum.

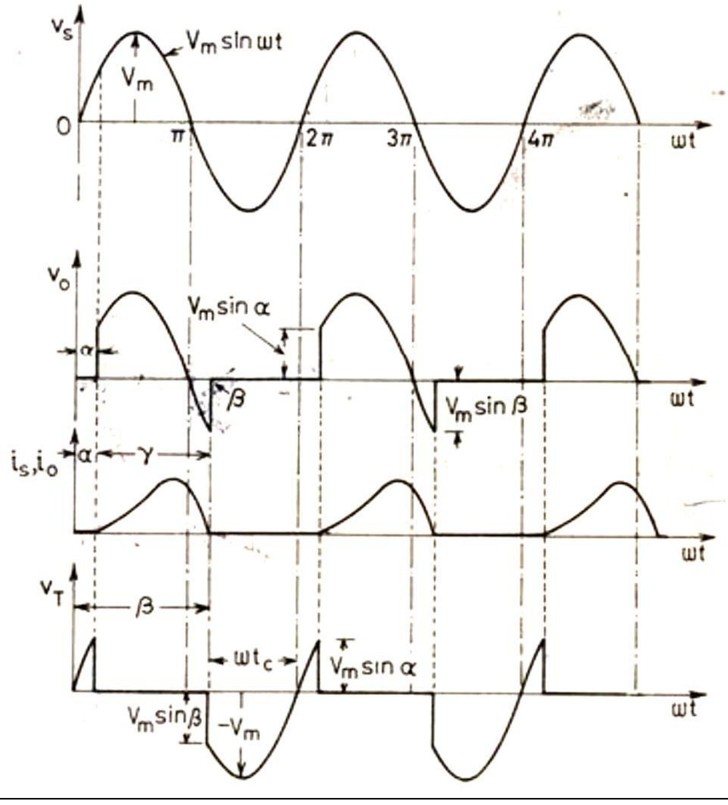
- ✓ This pulsating DC means that the equivalent DC value dropped across the load resistor, R_L is therefore only one half of the sinusoidal waveforms average value. Since the maximum value of the waveforms sine function is 1 (sin(90°)), the Average or Mean DC value taken over one-half of a sinusoid is defined as: 0.637 x maximum amplitude value.
- ✓ So during the positive half-cycle, A_{AVE} equals 0.637*A_{MAX}. However as the negative half-cycles are removed due to rectification by the diode, the average value during this period will be zero as shown.

Single Phase Half controlled converter with RL

- ✓ Mode (0 to π) - During positive half cycle, anode is connected to the positive terminal of the supply and the• cathode is connected to negative terminal of supply and the thyristor is forward biased. When the thyristor is fired at a firing angle (α), the load current will increase in a finite-time• through the inductive load. The supply voltage from this instant appears across the load.• Due to inductive load, the increase in current is gradual. Energy is stored in inductor during time t• 01to t1. At t1, the supply voltage reverses, but the thyristor is kept conducting because current through the• inductance cannot be reduced to zero.

- ✓ Mode (π to 2 π) - During negative half cycle, anode is connected to the negative terminal of the supply and the• cathode is connected to positive terminal of supply and the thyristor is reverse biased. Current continues to flow till the energy stored in the inductance is dissipated in the load-resistor• and a part of the energy is fed-back to the source. Hence due to energy stored in the inductor, current continues to flow up to instant t11.• At instantt11, the load-current is zero and due to negative supply voltage, thyristor turns off.•





- ✓ Output current iorises gradually. After some time io reaches a maximum value and then begins to decrease. At π, vo=0 but io is not zero because of the load inductance L. After π interval SCR is reverse biased but load current is not less then the holding current.
- ✓ At β>π, io reduces to zero and SCR is turned off. At 2π+β SCR triggers again α is the firing angle. β is the extinction angle. V = β - α conduction angle

a) **Average output voltage**

$$V_o(avg) = \frac{1}{2\pi} \int_0^{2\pi} V_m \sin \omega t \, d(\omega t)$$

where V_m is the peak value of the AC input voltage.

$$V_o(avg) = \frac{1}{2\pi} \left[\int_\alpha^{\pi} V_m \sin \omega t \, d(\omega t) + \int_\pi^{\theta} V_m \sin \omega t \, d(\omega t) + \int_\theta^{2\pi} V_m \sin \omega t \, d(\omega t)\right]$$

$$V_o(avg) = \frac{1}{2\pi} V_m \left([-\cos \omega t]_\alpha^{\pi} + [-\cos \omega t]_\pi^{\theta}\right) \qquad \{\theta = \beta - \pi\}$$

$$\boxed{V_o(avg) = \frac{Vm}{2\pi} [\cos\alpha - \cos\beta]}$$

b) **Average Output current**

$I_o(avg) = V_o(avg)/R$

$$\boxed{I_o(avg) = = \frac{Vm}{2\pi} [\cos\alpha - \cos\beta]/R}$$

c) **RMS Output Voltage**

$$V_o(rms) = \left[\frac{1}{2\pi} \int_0^{2\pi} Vm^2 \sin^2 \omega t \, d(\omega t)\right]^{1/2}$$

$$V_o(rms) = \frac{1}{2\pi} \left[\int_\alpha^{\pi} V_m^2 \sin^2 \omega t \, d(\omega t) + \int_\pi^{\theta} V_m^2 \sin^2 \omega t \, d(\omega t) + \int_\theta^{2\pi} V_m^2 \sin^2 \omega t \, d(\omega t)\right]^{1/2}$$

$$\boxed{V_o(rms) = \frac{Vm}{\sqrt{2}} \left[\frac{\beta-\alpha}{\pi} + \frac{\sin 2\alpha - \sin 2\beta}{2\pi}\right]^{1/2}}$$

Video Content / Details of website for further learning (if any):

- https://www.philadelphia.edu.jo/academics/mlazim/uploads/PE%20Lecture%20No.07.pdf
- https://www.youtube.com/watch?v=EYBFub4JD3Y

Important Books/Journals for further learning including the page nos.: 75-79

P.S.Bimbra "Power Electronics" Khanna Publishers, third Edition, 2003.

Course Faculty

L12

LECTURE HANDOUTS

EEE

III / V

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit II : AC - DC Converters **Date of Lecture:**

Topic of Lecture:

Single Phase Half controlled converter RLE Load

Introduction :

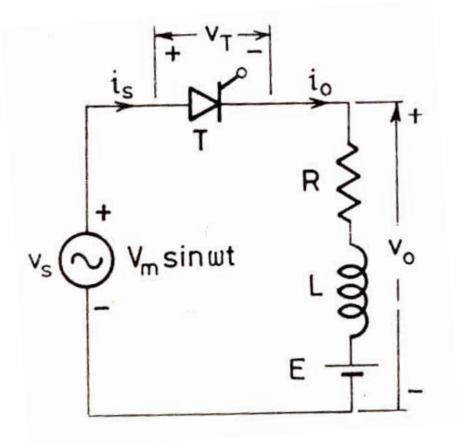
- Rectification converts an oscillating sinusoidal AC voltage source into a constant current DC voltage supply by means of diodes, thyristors, transistors, or converters. This rectifying process can take on many forms with half-wave, full-wave, uncontrolled and fully-controlled rectifiers transforming a single-phase or three-phase supply into a constant DC level

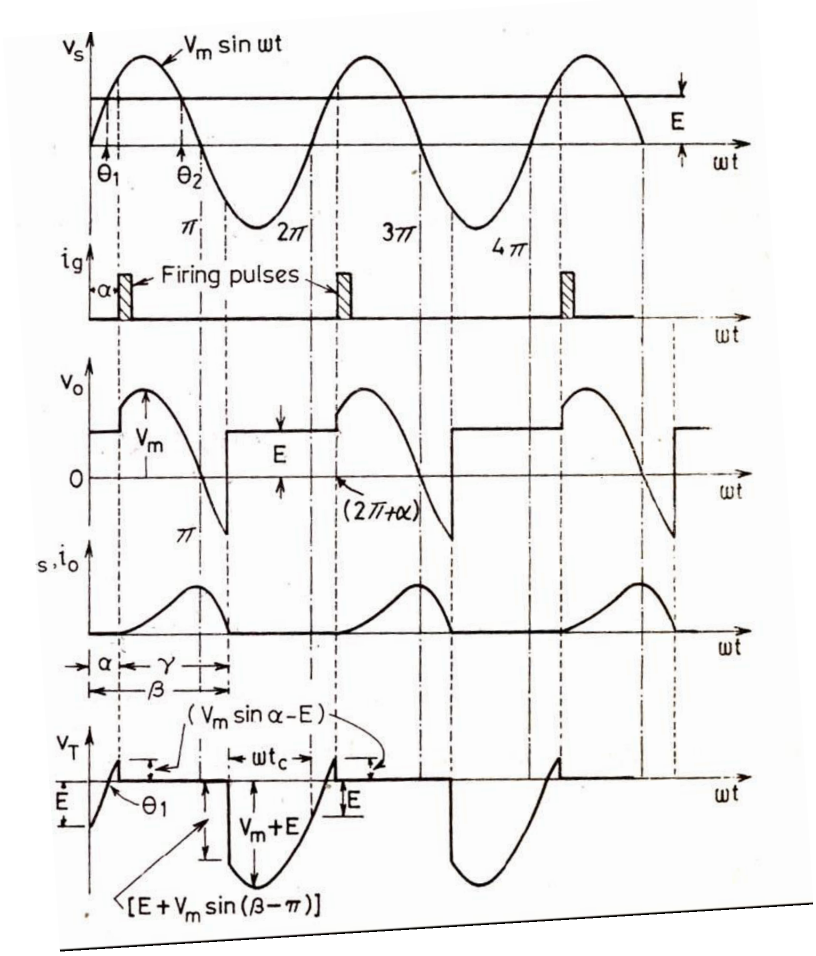
Prerequisite knowledge for Complete understanding and learning of Topic:

- Rectifier
- Switching devices

Single Phase Half controlled converter RLE Load

- ✓ In this Half wave rectifier, freewheeling diode is connected in parallel with the load. This diode is described as a commutating diode, flywheel diode or by-pass diode .This diode is commonly described as a commutating diode as its function is to commutate or transfer load current away from the rectifier whenever the load-voltage goes into a reverse-state.
- ✓ This diode serves two main functions: I) It prevents reversal of load voltage except for small diode voltage-drop. ii) It transfers the load current away from the main rectifier, thereby allowing all of its thyristors to regain their blocking state
- ✓ Operation - With freewheeling diode Df , thyristor will not be able to conduct beyond 180, Induced voltage in inductance will change its polarity as di/dt changes its sign and diode, Df will start conducting as soon as the induced voltage is of sufficient magnitude, thereby enabling the inductance to discharge its stored energy into the resistance.
- ✓ Here after 180, the load current will freewheel through the diode and a reverse-voltage• will appear across the thyristor. The power floe from the input takes place only when the thyristor is conducting.
- ✓ It is one of the most popular converter circuits and is widely used in the speed control of separately excited dc machines. Indeed, the R–L–E load shown in this figure may represent the electrical equivalent circuit of a separately excited dc motor.
- ✓ The single phase fully controlled bridge converter is obtained by replacing all the diode of the corresponding uncontrolled converter by thyristors. Thyristors T1 and T2 are fired together while T3 and T4 are fired 180º after T1 and T2.





- ✓ From the circuit diagram of figure it is clear that for any load current to flow at least one thyristor from the top group (T1, T3) and one thyristor from the bottom group (T2, T4) must conduct. It can also be argued that neither T1T3 nor T2T4 can conduct simultaneously. For example whenever T3 and T4 are in the forward blocking state and a gate pulse is applied to them, they turn ON and at the same time a negative voltage is applied across T1 and T2 commutating them immediately. Similar argument holds for T1 and T2.
- ✓ For the same reason T1T4 or T2T3 can not conduct simultaneously. Therefore, the only possible conduction modes when the current i0 can flow are T1T2 and T3T4. Of coarse it is possible that at a given moment none of the thyristors conduct. This situation will typically occur when the load current becomes zero in between the firings of T1T2 and T3T4. Once the load current becomes zero all thyristors remain off. In this mode the load current remains zero. Consequently the converter is said to be operating in the discontinuous conduction mode.
- ✓ Figure shows the voltage across different devices and the dc output voltage during each of these conduction modes. It is to be noted that whenever T1 and T2 conducts, the voltage across T3 and T4 becomes –vi. Therefore T3 and T4 can be fired only when vi is negative i.e, over the negative half cycle of the input supply voltage. Similarly T1 and T2 can be fired only over the positive half cycle of the input supply. The voltage across the devices when none of the thyristors conduct depends on the off state impedance of each device.

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=rc-94-8RpzU
- https://www.philadelphia.edu.jo/academics/mlazim/uploads/PE%20Lecture%20No.07.pdf

Important Books/Journals for further learning including the page nos.: 80-84
P.S.Bimbra "Power Electronics" Khanna Publishers, third Edition, 2003.

Course Faculty

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit II : AC - DC Converters **Date of Lecture:**

Topic of Lecture:

Single Phase Full controlled converter R and RL Load

Introduction :

- Phase controlled rectification uses combinations of diodes and thyristors (SCR's) to convert the AC input voltage into a controlled DC output voltage. Fully-controlled rectifiers use four thyristors in their configuration, whereas half-controlled rectifiers use a combination of both thyristors and diodes.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Phase controlled rectification
- Operation of thyristors

Single Phase Full controlled converter R

Two Pulse Converters:

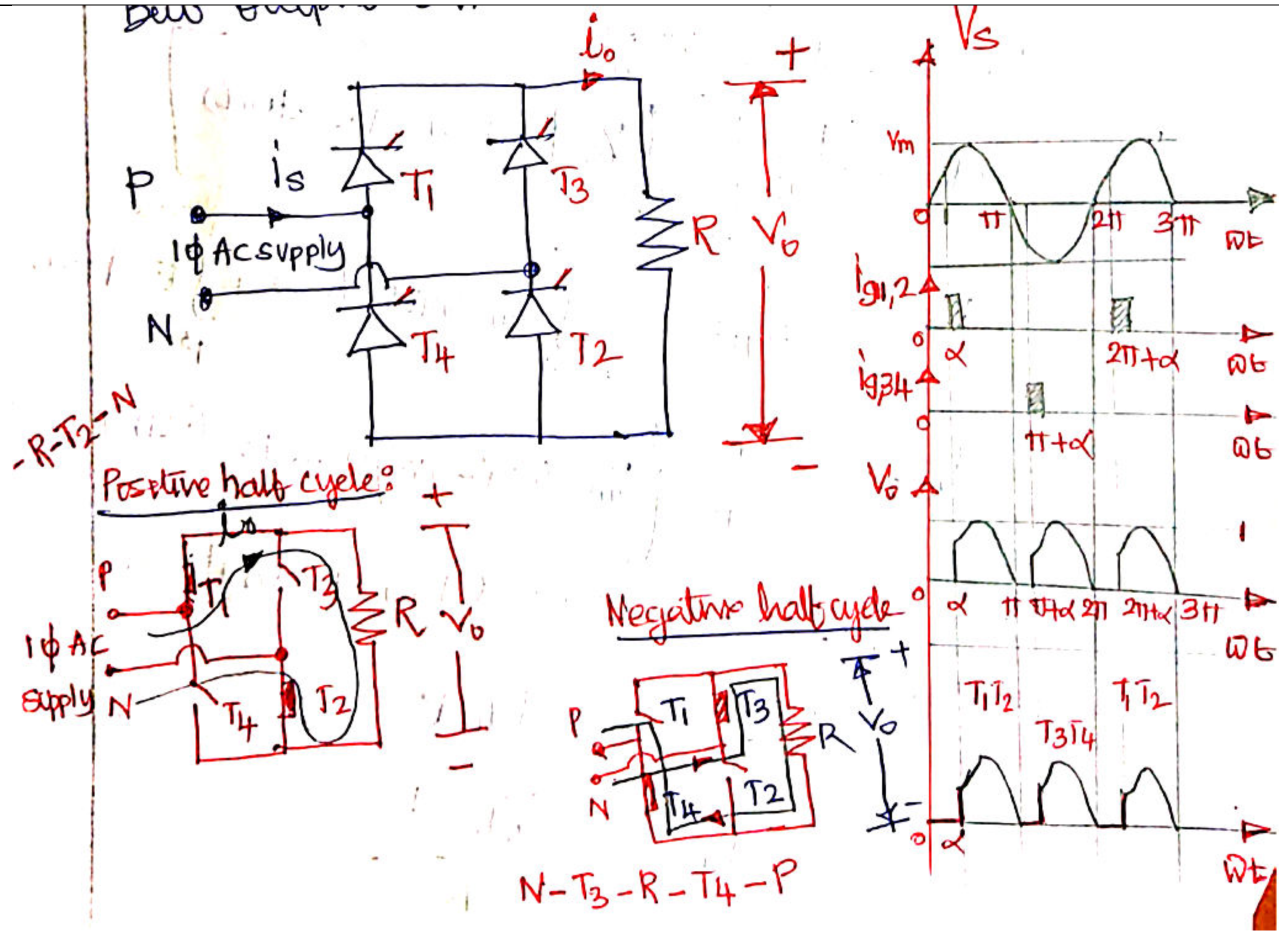
Two pulse converter can be classified as

1) 1φ FWCC
   a) mid-point converter
   b) Bridge converter
2) 1φ HCC (semiconverter)

1φ FWCC – R load.

Single phase FW controlled rectifier is also called as two quadrant converter, A Fully controlled converter or full converter uses thyristors only and there is a wider control over the level of dc output voltage.

output voltage is either positive or negative but output current is always positive



1) Average output voltage (V_{dc})

$$V_{dc} = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \, d(\omega t)$$

$$= \frac{V_m}{\pi}\left(-\cos\omega t\right)_{\alpha}^{\pi}$$

$$V_{dc} = \frac{V_m}{\pi}(1+\cos\alpha)$$

2) Average load current (I_{dc})

$$I_{dc} = \frac{V_{dc}}{R} = \frac{V_m}{\pi R}(1+\cos\alpha)$$

3) Rms load voltage (V_{orms})

$$V_{orms} = \left[\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$$

$$= V_m\left[\frac{1}{\pi}\int_{\alpha}^{\pi}\left(\frac{1-\cos 2\omega t}{2}\right) d(\omega t)\right]^{1/2}$$

$$= V_m\left[\frac{1}{2\pi}\left(\omega t - \frac{\sin 2\omega t}{2}\right)_{\alpha}^{\pi}\right]^{1/2}$$

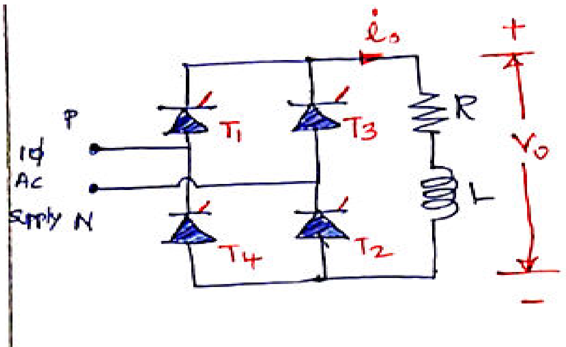
$$= V_m\left[\frac{1}{2\pi}\left(\pi-\alpha + \frac{\sin 2\alpha - \sin 2\pi}{2}\right)\right]^{1/2}$$

$$V_{orms} = V_m\left[\frac{\pi-\alpha}{2\pi} + \frac{\sin 2\alpha}{4\pi}\right]^{1/2}$$

4) Rms load current (I_{rms})

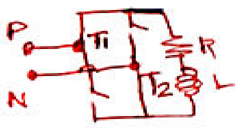
$$I_{orms} = \frac{V_{orms}}{R}$$

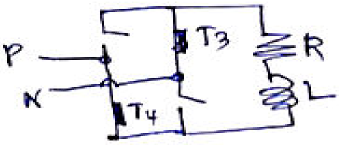
Single Phase Full controlled converter with RL



Inductor L is used in this circuit to reduce the ripple. A large value of inductor L is used for continuous steady current in the load.

During positive half cycle, Thyristor T_1 and T_2 triggered current flow through the path $P - T_1 - RL - T_2 - N$.





$N - T_3 - RL - T_4 - P$

MODE 1: Rectification Mode ($\alpha < 90°$)

During the interval α to π, both supply voltage and supply current are positive, ∴ Power to the load also positive.

During the interval π to $(\pi + \alpha)$, V_s is −ive but I_s is +ive, ∴ the load returns some of its energy to the supply system.

IF $\alpha < 90°$ — Power flow from source to load and convert AC to DC and operates as a **RECTIFIER**

MODE 2: Inversion mode

$\alpha > 90$ — Power flow from load to source now its operates as a **Inverter**

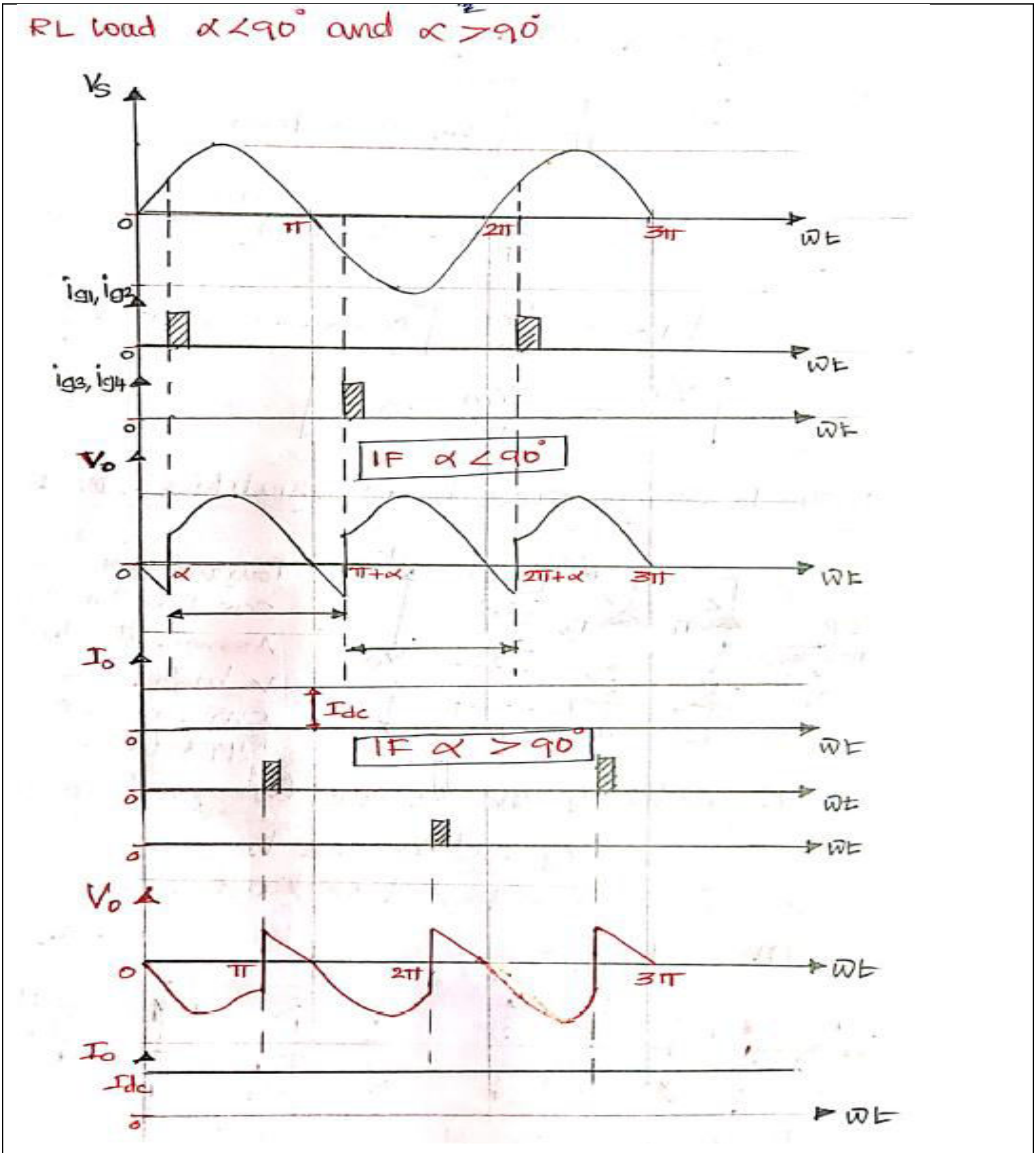
Average output voltage (V_{dc})

$$V_{dc} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin \omega t \, d(\omega t)$$

$$= \frac{V_m}{\pi}\left(-\cos \omega t\right)_{\alpha}^{\pi+\alpha}$$

$$V_{dc} = \frac{V_m}{\pi}\left[\cos\alpha - \cos(\pi+\alpha)\right]$$

$$\boxed{V_{dc} = \frac{2V_m}{\pi}\cos\alpha}$$



Video Content / Details of website for further learning (if any):

- https://nptel.ac.in/content/storage2/courses/108105066/PDF/L-10(DK)(PE)%20((EE)NPTEL).pdf

Important Books/Journals for further learning including the page nos.: 91-96

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Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

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L14

LECTURE HANDOUTS

EEE | **III / V**

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit II : AC - DC Converters **Date of Lecture:**

Topic of Lecture:

Single Phase Full controlled converter RLE Load

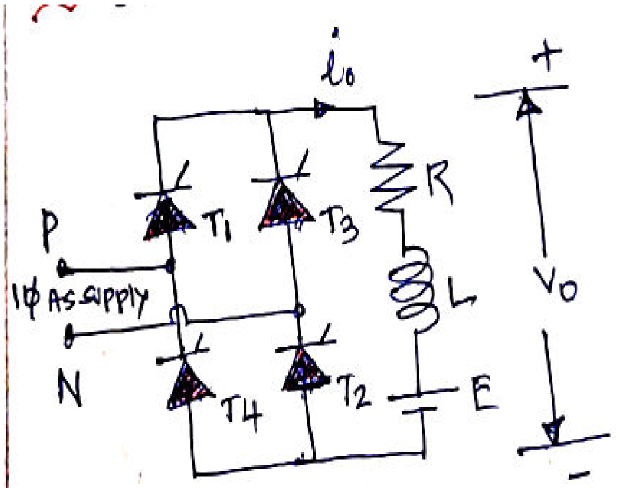
Introduction :

- Rectification converts an oscillating sinusoidal AC voltage source into a constant current DC voltage supply by means of diodes, thyristors, transistors, or converters. This rectifying process can take on many forms with full-wave fully-controlled rectifiers transforming a single-phase or three-phase supply into a constant DC level

Prerequisite knowledge for Complete understanding and learning of Topic:

- Rectifier
- Switching devices

Single Phase Full controlled converter RLE Load



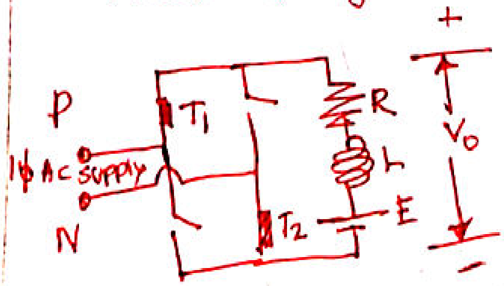
Power circuit consists of four SCR T_1 to T_4 and RLE load. Assume the load inductance is high, Due to this load current is continuous and Ripple free.

Thyristor T_1 and T_2 are triggered at $\omega t = \alpha$

T_3 and T_3 are triggered at $\omega t = \alpha$ to $\pi+\alpha$

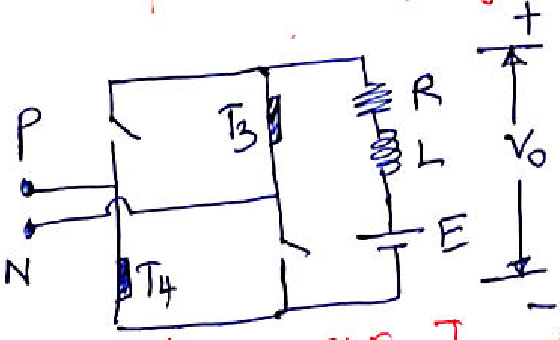
the conduction period of the thyristor is 180°

+ive half cycle

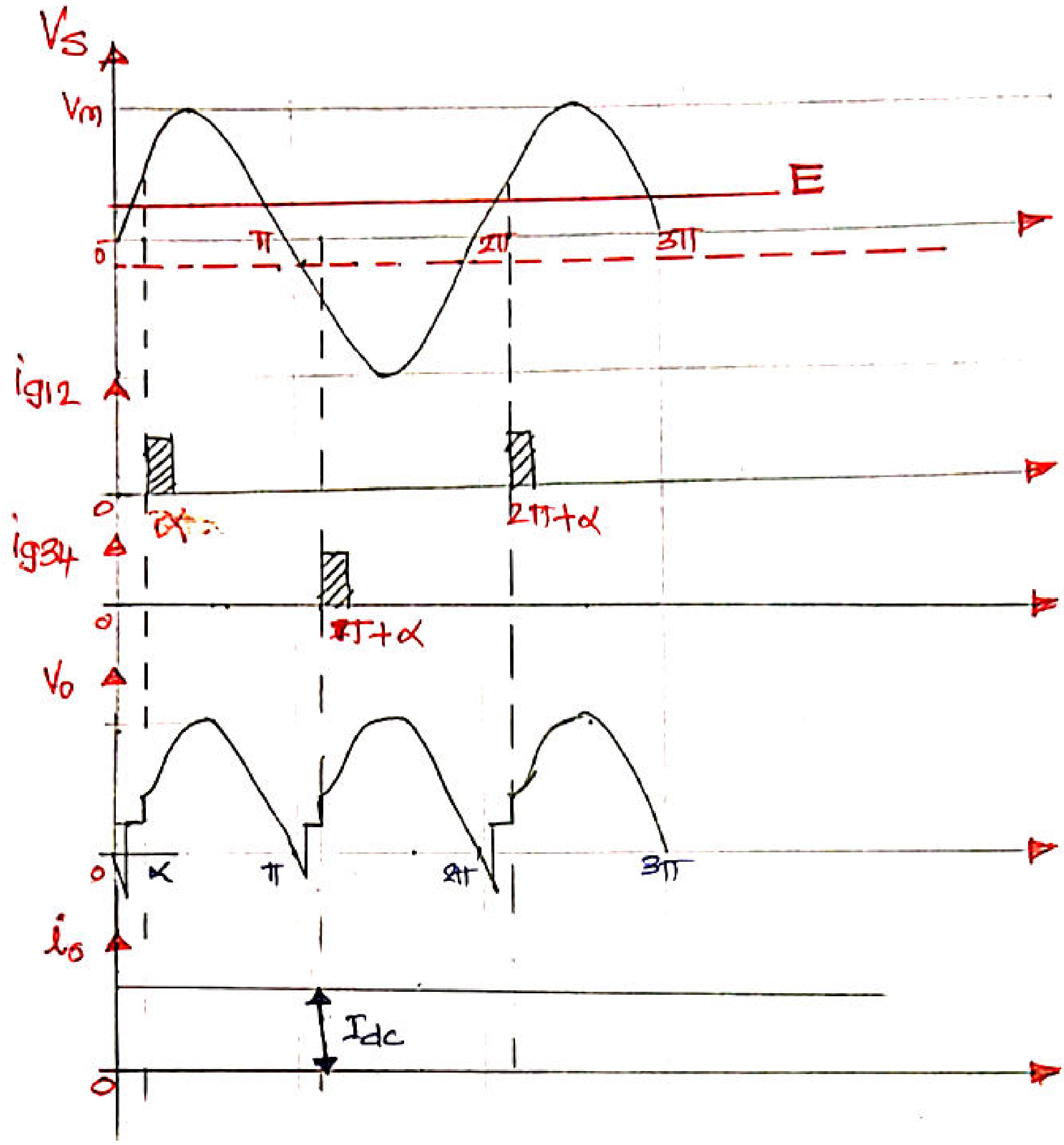


P – T_1 – RLE – T_2 – N

–ive half cycle.



N – T_3 – RLE – T_4 – P



Thyristor T_1 and T_2 triggered at $\omega t = \alpha$

(these SCRs will get turned on only if $V_m \sin\alpha > E$)

Average output voltage:

$$V_{dc} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t \, d(\omega t) = \frac{V_m}{\pi}\int_{\alpha}^{\pi+\alpha} \sin\omega t \, d(\omega t)$$

$$V_{dc} = \frac{2V_m}{\pi}\cos\alpha$$

Average output current:

$$I_{dc} = \frac{V_{dc} - E}{R}$$

Rms output voltage

$$V_{orms} = \left[\frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$$

$$V_{orms} = \frac{V_m}{\sqrt{2}} \text{ (or) } V_s$$

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=rc-94-8RpzU
- https://www.philadelphia.edu.jo/academics/mlazim/uploads/PE%20Lecture%20No.07.pdf

Important Books/Journals for further learning including the page nos.: 103-107

P.S.Bimbra "Power Electronics" Khanna Publishers, third Edition, 2003

Course Faculty

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit II : AC - DC Converters **Date of Lecture:**

Topic of Lecture:

Single Phase FCC / HCC with freewheeling diode

Introduction :

- A fly back or freewheeling diode reduces harmonics and also suppress the voltage spikes occur in inductive load. It is also called snubber diode, suppressor diode, catch diode or clamp diode, commutating diode. Schottky diodes are used as freewheeling diode.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Operation of Half controlled converter
- Operation of Full controlled converter

1ϕ FCC / HCC with freewheeling diode

- ✓ In a phase controlled rectifier the waveform of voltages may be compared to know the effect Without freewheeling diode the output voltage becomes negative polarity while the current continues to decrease but in the same direction as that of previous half cycle… This results in the power being delivered by the load

$$V_0 = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin(\omega t)\, d(\omega t)$$

$$= \frac{V_m}{\pi}\cos\alpha$$

steady state analysis

$$V_s = Ri_o + L\frac{di_0}{dt} + E$$

$$V_0 = RI_0 + E$$

$$V_0 = \frac{2V_m}{\pi}\cos\alpha$$

So in case of DC motor load

$$V_0 = r_a I_a + \alpha_m \omega_m$$

So $$\omega_m = \frac{\frac{2V_m}{\pi}\cos\alpha - r_a I_a}{\alpha_m}$$

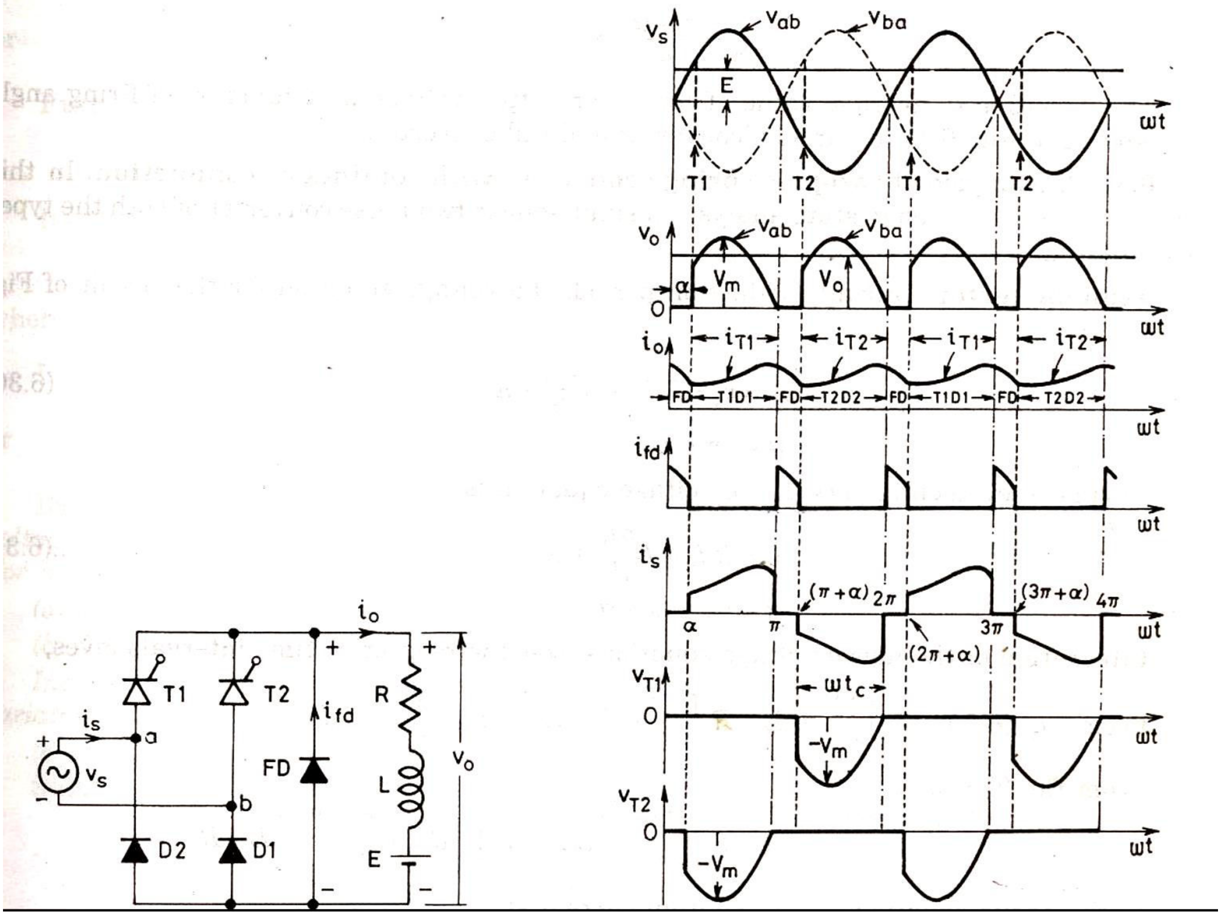
$$T = \alpha_m I_a$$

$$\Rightarrow I_a = \frac{T_e}{\alpha_m}$$

Put $$I_a = \frac{T_e}{\alpha_m}$$

So $$\omega_m = \frac{(\frac{2V_m}{\pi})\cos\alpha}{\alpha_m} - \frac{r_a T_e}{\alpha_m^2}$$

- ✓



- ✓ A Flyback diode is also called as freewheeling diode. It is also called by many other names like snubber diode, suppressor diode, catch diode or clamp diode, commutating diode. Here catch diode is used to eliminate flyback, when the abrupt voltage spike is witnessed across the inductive load when the supply current abruptly reduced. It helps the circuit from damaging. It will get prevented from buying new circuit. Freewheeling diode is simplified form where voltage source is connected to an inductor with a switch.
- ✓ The working principle of freewheeling diode will be simple and will be explained with three circuits. That will make clear understanding how it actually works. In the steady-state, the switch will be closed for a long time so, that the inductor gets fully energized and behaves as though it is a short
- ✓ The diode will be reversed biased when the switch is closed against the power supply and which doesn't exist in the circuit for practical purposes. However, the diode becomes forward-biased when the switch is opened, in relative to the inductor, and allows conducting current in a circular loop from the positive potential at the bottom of the inductor to the negative potential at the top. The voltage across the inductor will be a function of the forward voltage drop of the Flyback diode. Total time for dissipation may vary, but it will last for a few milliseconds

Video Content / Details of website for further learning (if any):

- https://www.elprocus.com/freewheeling-or-flyback-diode-circuit-working-functions

Important Books/Journals for further learning including the page nos.: 107-110

P.S.Bimbra "Power Electronics" Khanna Publishers, third Edition, 2003.

Course Faculty

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Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS

L16

EEE

III / V

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit II : AC - DC Converters **Date of Lecture:**

Topic of Lecture:

3 Phase HCC with R, RL, & RLE load

Introduction :

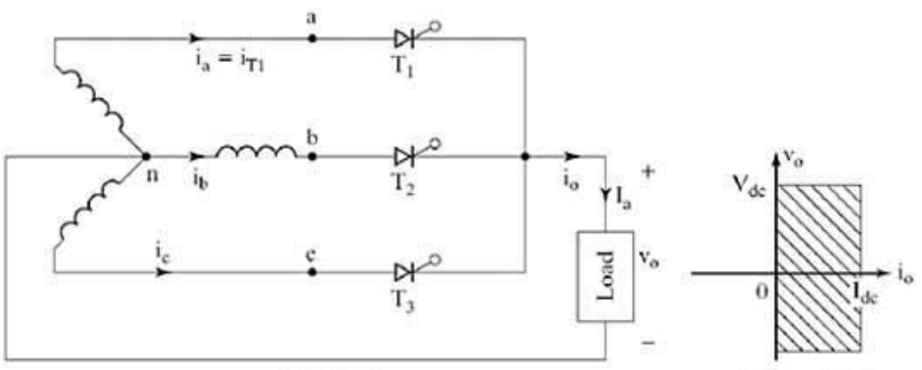
- Although the thyristor is extensively used in high power applications, it always suffered from being a semi-controlled device. Even though it could be switched ON by applying a gate signal, it has to be turned OFF by interrupting the main current using a commutation circuit.

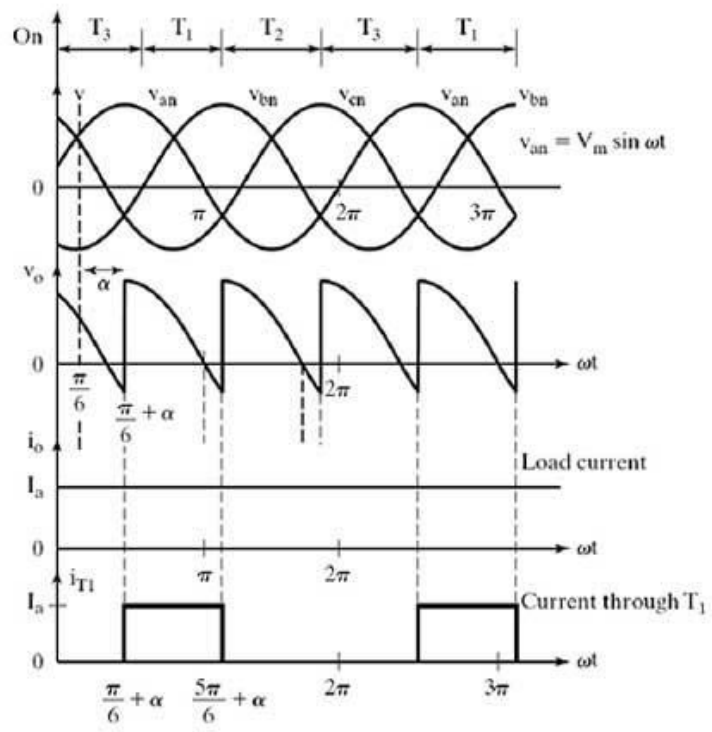
Prerequisite knowledge for Complete understanding and learning of Topic:

- Behavior of Resistive, inductive and capacitive loads
- Half controlled converter

3 Phase Half controlled converter

- ✓ The 3-phase half wave converter combines three single phase half wave controlled rectifiers in one single circuit feeding a common load. The thyristor T1 in series with one of the supply phase windings 'a-n' acts as one half wave controlled rectifier. The second thyristor T2 in series with the supply phase winding 'b-n' acts as the second half wave controlled rectifier. The third thyristor T3 in series with the supply phase winding acts as the third half wave controlled rectifier.
- ✓ The 3-phase input supply is applied through the star connected supply transformer as shown in the figure. The common neutral point of the supply is connected to one end of the load while the other end of the load connected to the common cathode point.
- ✓





- ✓ When the thyristor T1 is triggered at $\omega t=(\prod/6 + \alpha)=(30° + \alpha)$, the phase voltage Van appears across the load when T1 conducts. The load current flows through the supply phase winding 'a-n' and through thyristor T1 as long as T1 conducts.
- ✓ When thyristor T2 is triggered at $\omega t=(5\prod/6\alpha)$, T1 becomes reverse biased and turns-off. The load current flows through the thyristor and through the supply phase winding 'b-n' . When T2 conducts the phase voltage vbn appears across the load until the thyristor T3 is triggered .
- ✓ When the thyristor T_3 is triggered at $\omega t=(3\prod/2 + \alpha)=(270°+\alpha)$, T_2 is reversed biased and hence T_2 turns-off. The phase voltage V_{an} appears across the load when T_3 conducts.
- ✓ When T_1 is triggered again at the beginning of the next input cycle the thyristor T_3 turns off as it is reverse biased naturally as soon as T_1 is triggered. The figure shows the 3-phase input supply voltages, the output voltage which appears across the load, and the load current assuming a constant and ripple free load current for a highly inductive load and the current through the thyristor T_1.
- ✓ For a purely resistive load where the load inductance 'L = 0' and the trigger angle $\alpha >(\prod/6)$, the load current appears as discontinuous load current and each thyristor is naturally commutated when the polarity of the corresponding phase supply voltage reverses. The frequency of output ripple frequency for a 3-Phase Half Wave Converter is fs, where fs is the input supply frequency. The 3-Phase half wave converter is not normally used in practical converter systems because of the disadvantage that the supply current waveforms contain dc components (i.e., the supply current waveforms have an average or dc value

Video Content / Details of website for further learning (if any):

- https://nptel.ac.in/content/storage2/courses/108105066/PDF/L-14(DK)(PE)%20((EE)NPTEL).pdf

Important Books/Journals for further learning including the page nos.: 120-124

P.S.Bimbra "Power Electronics" Khanna Publishers, third Edition, 2003.

Course Faculty

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L17

LECTURE HANDOUTS

EEE | **III / V**

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit II : AC - DC Converters **Date of Lecture:**

Topic of Lecture:

3 Phase FCC with R, RL, & RLE load

Introduction : (Maximum 5 sentences)

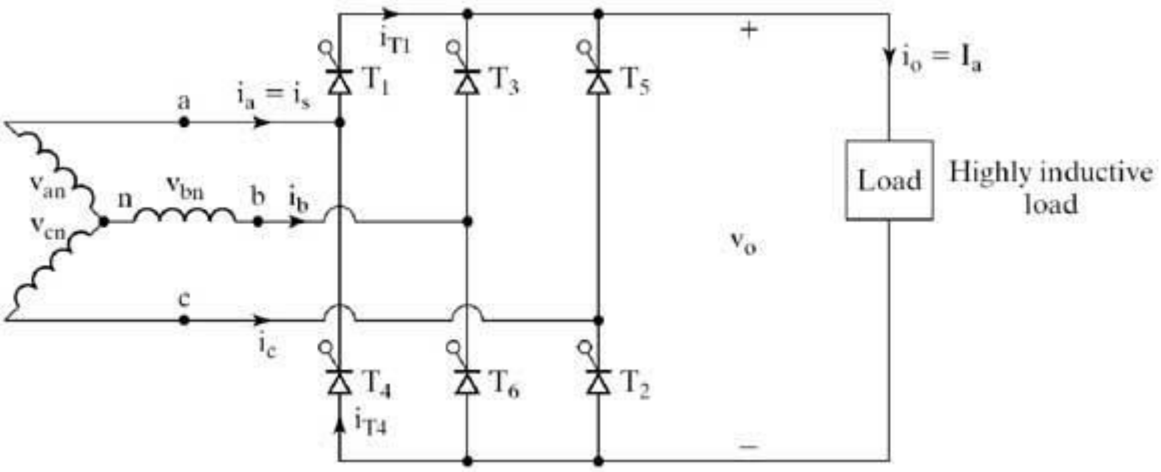
- Three Phase Full Converter is a fully controlled bridge controlled rectifier using six thyristors connected in the form of a full wave bridge configuration. All the six thyristors are controlled switches which are turned on at a appropriate times by applying suitable gate trigger signals.

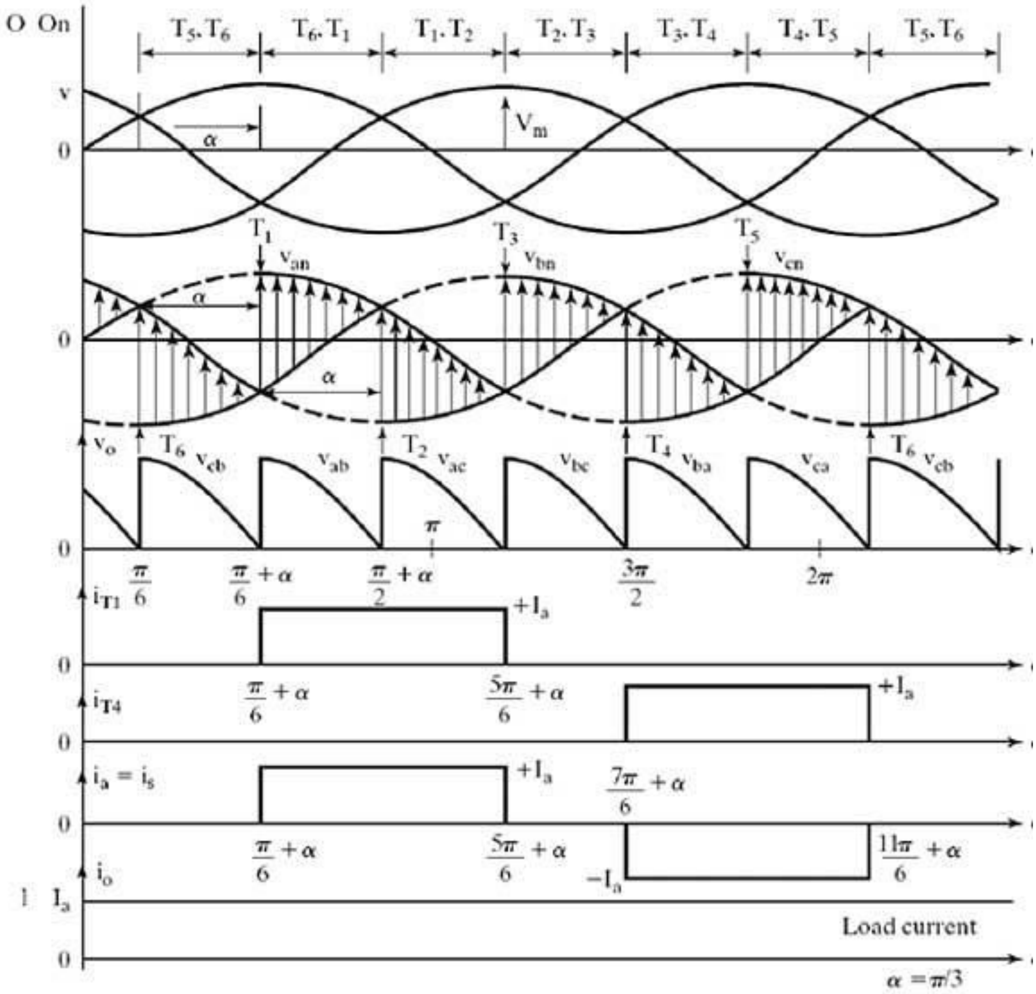
Prerequisite knowledge for Complete understanding and learning of Topic:

- Behavior of Resistive, inductive and capacitive loads
- Half controlled converter

3 Phase Full controlled converter

- ✓ The three phase full converter is extensively used in industrial power applications upto about 120kW output power level, where two quadrant operations is required. The figure shows a three phase full converter with highly inductive load. This circuit is also known as three phase full wave bridge or as a six pulse converter.
- ✓ The thyristors are triggered at an interval of (∏/3) radians (i.e. at an interval of 30°). The frequency of output ripple voltage is $6f_s$ and the filtering requirement is less than that of three phase semi and half wave converters.





- ✓ At $\omega t=(\prod/6\ +a)$, thyristor is already conducting when the thyristor is turned on by applying the gating signal to the gate of . During the time period $\omega t=(\prod/6 +a)$ to $(\prod/2 +\alpha)$, thyristors and conduct together and the line to line supply voltage appears across the load.
- ✓ At $\omega t=(\prod/2\ +a)$, the thyristor T_2 is triggered and T_6 is reverse biased immediately and T_6 turns off due to natural commutation. During the time period $\omega t=(\prod/ +a)$ *to* $(5\prod/6 +a)$, thyristor T_1 and T_2 conduct together and the line to line supply voltage appears across the load.
- ✓ The thyristors are numbered in the circuit diagram corresponding to the order in which they are triggered. The trigger sequence (firing sequence) of the thyristors is 12, 23, 34, 45, 56, 61, 12, 23, and so on. The figure shows the waveforms of three phase input supply voltages, output voltage, the thyristor current through T_1 and T_4, the supply current through the line ‘a’.

Video Content / Details of website for further learning (if any):

- https://www.pantechsolutions.net/introduction-of-three-phase-half-full-wave-converter

Important Books/Journals for further learning including the page nos.: 128-133

P.S.Bimbra “Power Electronics” Khanna Publishers, third Edition, 2003.

Course Faculty

L18

LECTURE HANDOUTS

EEE **III / V**

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit II : AC - DC Converters **Date of Lecture:**

Topic of Lecture:

Effect of Source Inductance

Introduction :

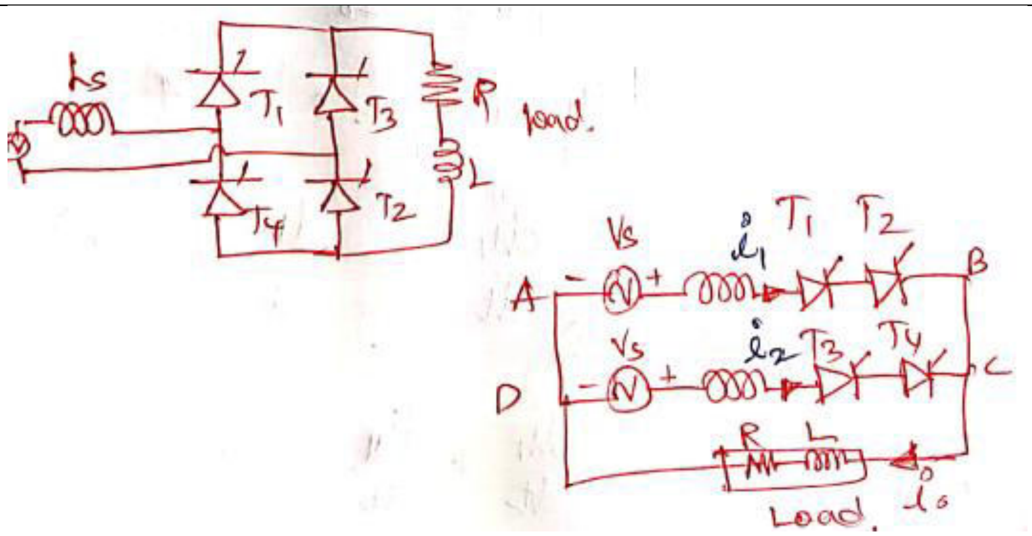
- Source inductance has a significant impact on the converter performance because its presence alters the output voltage of the converter. As a result, the output voltage reduces as the load current reduces. In addition, the input current and output voltage waveforms change significantly.

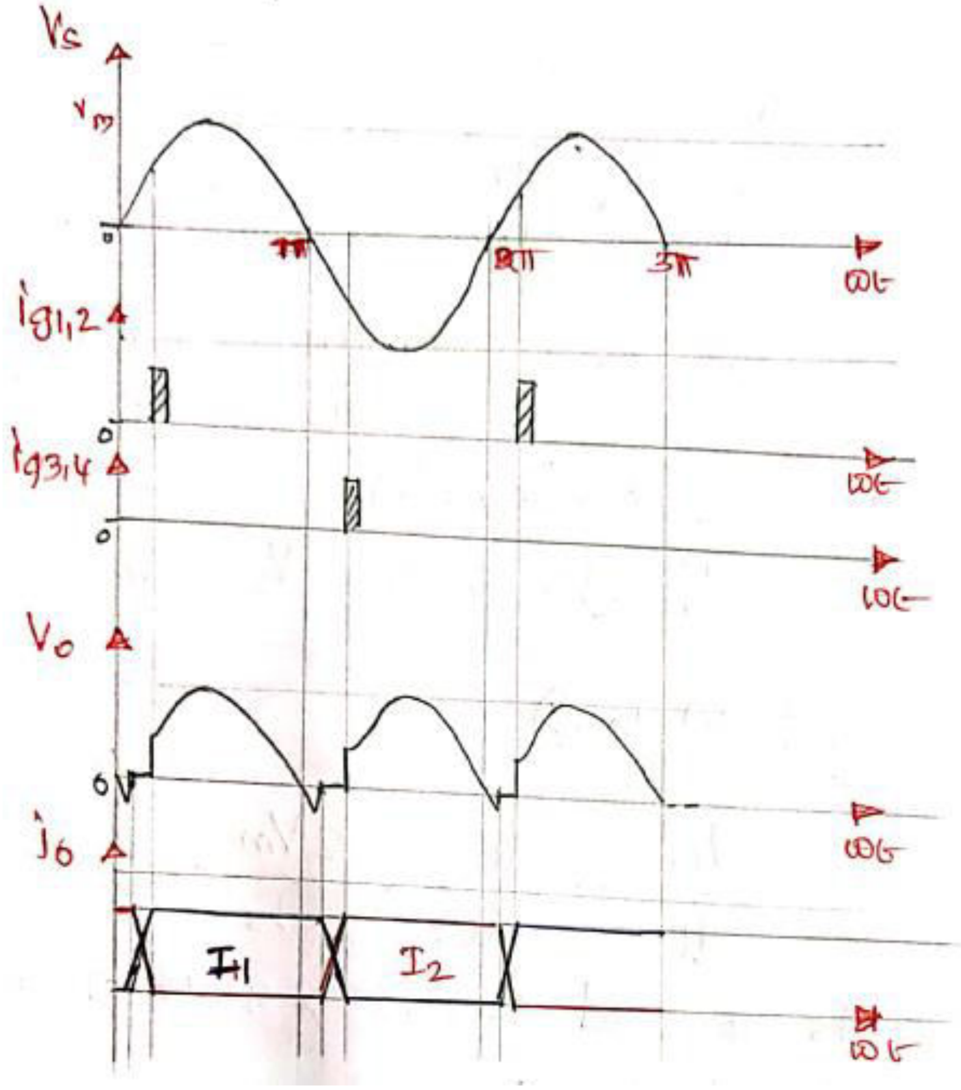
Prerequisite knowledge for Complete understanding and learning of Topic:

- Property of inductor
- Switching behaviors of the converter

Effect of Source Inductance

- ✓ Assuming that the converter operates in conduction mode and the ripple from the load current is negligible, the open circuit voltage becomes equal to average DC output at a firing angle of α.The diagram below shows a fully controlled converter with source in single phase. The thyristors T3 and T4 are assumed to be in conduction mode when t = 0. On the other hand, T1 and T2 fire when $\omega t = \alpha$
- ✓ When there is no source inductance, commutation will occur at T_3 and T_4. Immediately thyristors T_1 and T_2 are switched ON. This will lead the input polarity to change instantaneously. In the presence of source inductance, change of polarity and commutation does not occur instantaneously. Thus, T_3 and T_4 do not commutate as soon as T_1 and T_2 are switched ON.
- ✓ At some interval, all the four thyristors will be conducting. This conducting interval is called the overlap interval μ. The overlap during commutation reduces the DC output voltage and the angle of extinction γ resulting in failed commutation when αis close to 180°. This is shown by the waveform





Video Content / Details of website for further learning (if any):

- https://www.electronicshub.org/scr-protection/

Important Books/Journals for further learning including the page nos.: 135-138
P.S.Bimbra "Power Electronics" Khanna Publishers, third Edition, 2003.

Course Faculty

L19

LECTURE HANDOUTS

EEE **III/V**

Course Name with Code : 19EED07 / Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit III : DC to DC Choppers **Date of Lecture:**

Topic of Lecture: Chopper Principle of operation

Introduction :

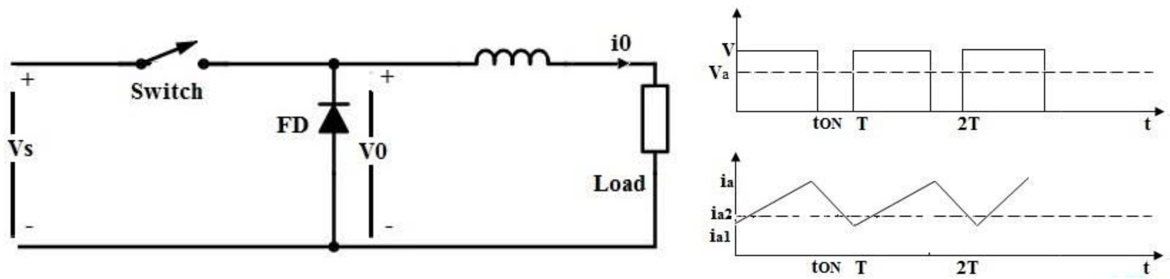
- As the invention and use of technological devices are increasing, our need for electricity is also increasing. To meet this need of continuous electricity various methods and systems are being introduced.
- Among the gadgets and devices we use, some are powered by AC current while some are of DC powered. Not all devices require the same amount of power to operate. But the power given to the households through main power supply is AC and of a fixed amount of about 240v.
- Then to operate devices that work on DC current some converters are required. To use only a small required amount of power from the 240V supply another type of circuit namely Chopper circuit is required.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Converter
- Switching Device

Chopper Principle of operation

- Chopper circuits are known as DC to DC converters. Similar to the transformers of the AC circuit, choppers are used to step up and step down the DC power. They change the fixed DC power to variable DC power. Using these, DC power supplied to the devices can be adjusted to the required amount.



Chopper Circuit

Principle of Operation

- The principle of operation of chopper can be understood from the circuit diagram below. The circuit consists of a semiconductor diode, resistor, and a load. For all type of chopper circuit, the output voltage value is controlled by periodic closing and opening of the switches used in the circuit.

- The chopper can be viewed as an ON/OFF switch that can rapidly connect or disconnect the source to load connection. Continuous DC is given as source to the chopper as Vs and chopped DC is obtained across the load as V0.

Output Voltage and Current Waveforms

- Above are the output voltage and current waveforms of a chopper circuit. From the voltage waveform, it can be seen that during the period of T_{ON} the load voltage V0 is equal to the source voltage Vs. But when the interval T_{OFF} occurs, the DC voltage step downs to zero, thus making the load short-circuited.
- In the current waveform, it can be seen that during the interval T_{ON} the load current rises to the maximum value. During the interval T_{OFF}, the load current decays. In T_{OFF} condition the chopper is off so, the load voltage becomes zero. But load current flows through the diode FD, making the load short-circuited.
- Thus, the chopped DC voltage is produced at the load. The current waveform is continuous which rises during T_{ON} state and decays during T_{OFF} state.

Classification of Chopper

- Based on their operation principle and type of source voltage chopper are of various types. The main classification of the chopper is DC chopper and AC Link chopper. Based on the commutation process they are classified as a natural commutated chopper and forced commutated chopper.
- Forced commutated chopper is further classified as Jones chopper, Morgan chopper. Based on output voltage values choppers are classified as a step down the chopper, step up chopper, step-up/down chopper. Based on the power loss occurred at switching time choppers are classified as Hard switched and soft switched.

1). AC Link Chopper

- In this classification of the chopper, the voltage inversion takes place. Here the DC voltage is converted into AC with the help of an inverter. Now this AC is passed through a step-down or step-up transformers. The output from the transformers is again converted into DC by a rectifier. AC link choppers are very bulky and occupy a large amount of space.

2).DC Chopper

- DC chopper works on DC voltage. They work as a step up and step down transformers on DC voltage. They can convert the steady constant DC voltage to a higher value or lower value based on their type.
- DC choppers are more efficient, speed and optimized devices. These can be incorporated on electronic chips. They provide smooth control over the DC voltage.

Different Types of Chopper Circuits

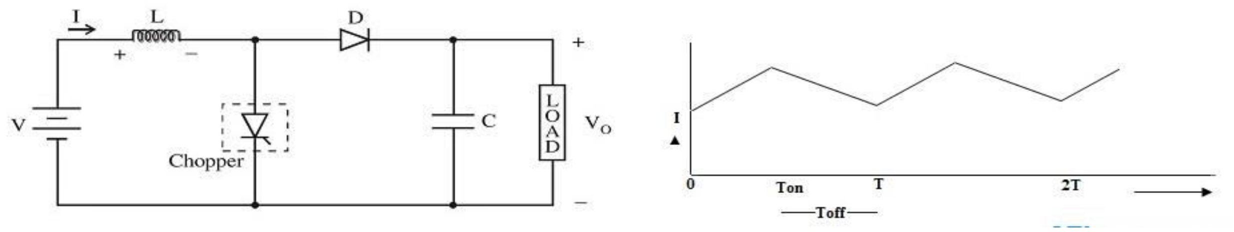
- The main element based on which choppers are categorized is the semiconductor used in the chopper circuit. Based on the positioning of this semiconductor, choppers can be made to work in any of the four quadrant conditions. Depending on the quadrant of operation choppers are categorized as Type A, B, C, D, and E
- Type A chopper works in the first quadrant. In this chopper, the voltage and current both are positive and flows in the same direction. Power from source to load and the

average output voltage is less than input DC voltage.

- Type B chopper works in the second quadrant. Here the load voltage is positive and current is negative. Power flows from load to source. This chopper is also known as a step-up chopper.
- Type C chopper is formed by parallel connection of Type A and Type B choppers.
- Type D chopper is the two quadrant type B chopper and Type E chopper is the fourth gradient chopper.

Step Up Chopper

- Step-up chopper works as a step-up transformer on DC current. This chopper is used when the output DC voltage has to be made higher than the input voltage.
- 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.



Step up Chopper

- When the chopper is ON, supply voltage VS is applied to the load .i.e. V0 = VS and inductor starts storing energy. At this condition load current raises from Imin to Imax.
- When the chopper is switched OFF, the supply voltage takes the path from L – D – Load – VS. During this period the inductor discharges the stored e.m.f through diode D to the load. Thus the total voltage at the load V0 = VS + Ldi/dt which s greater than the input voltage. Current changes from Imax to Imin.

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 $V_0 = \frac{V_S}{T - T_{ON}/T}$

Video Content / Details of website for further learning (if any):

- http://www.completepowerelectronics.com/chopper-principle-of-operation/

Important Books/Journals for further learning including the page nos.: 192-195

P.S.Bimbra “Power Electronics” Khanna Publishers, third Edition, 2003.

Course Faculty

Course Name with Code : 19EED07 / Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit III : DC to DC Choppers **Date of Lecture:**

Topic of Lecture: Step Up / Step Down Control and control strategy

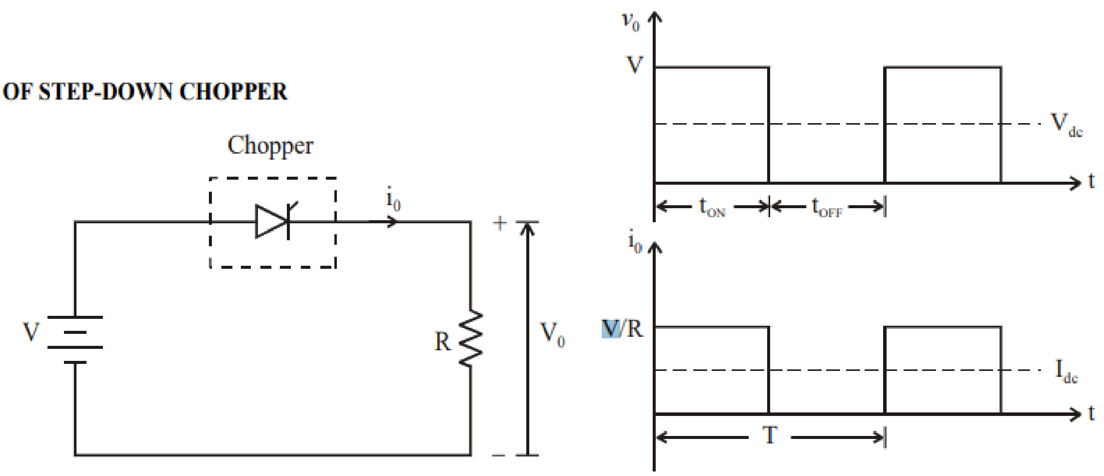
Introduction :

- A chopper is a static device which is used to obtain a variable dc voltage from a constant dc voltage source. A chopper is also known as dc-to-dc converter.
- The thyristor converter offers greater efficiency, faster response, lower maintenance, smaller size and smooth control. Choppers are widely used in trolley cars, battery operated vehicles, traction motor control, control of large number of dc motors, etc…..
- They are also used in regenerative braking of dc motors to return energy back to supply and also as dc voltage regulators.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Rectifier
- Triggering methods

PRINCIPLE OF STEP-DOWN CHOPPER



- The thyristor in the circuit acts as a switch. When thyristor is ON, supply voltage appears across the load and when thyristor is OFF, the voltage across the load will be zero. The output voltage and current waveforms.

V_{dc} = average value of output or load voltage

I_{dc} = average value of output or load current

t_{ON} = time interval for which SCR conducts

t_{OFF} = time interval for which SCR is OFF.

$T = t_{ON} + t_{OFF}$ = period of switching or chopping period

$f = \frac{1}{T} =$ frequency of chopper switching or chopping frequency.

Average output voltage

$$V_{dc} = V\left(\frac{t_{ON}}{t_{ON} + t_{OFF}}\right)$$

$$V_{dc} = V\left(\frac{t_{ON}}{T}\right) = V.d$$

but $\left(\frac{t_{ON}}{t}\right) = d =$ duty cycle

Average output current,

$$I_{dc} = \frac{V_{dc}}{R}$$

$$I_{dc} = \frac{V}{R}\left(\frac{t_{ON}}{T}\right) = \frac{V}{R}d$$

RMS value of output voltage

$$V_O = \sqrt{\frac{1}{T}\int_0^{t_{ON}} v_o^2 dt}$$

But during t_{ON}, $v_o = V$

Therefore RMS output voltage

$$V_O = \sqrt{\frac{1}{T}\int_0^{t_{ON}} V^2 dt}$$

$$V_O = \sqrt{\frac{V^2}{T}t_{ON}} = \sqrt{\frac{t_{ON}}{T}}.V$$

$$V_O = \sqrt{d}.V$$

Output power $P_O = V_O I_O$

But $I_O = \frac{V_O}{R}$

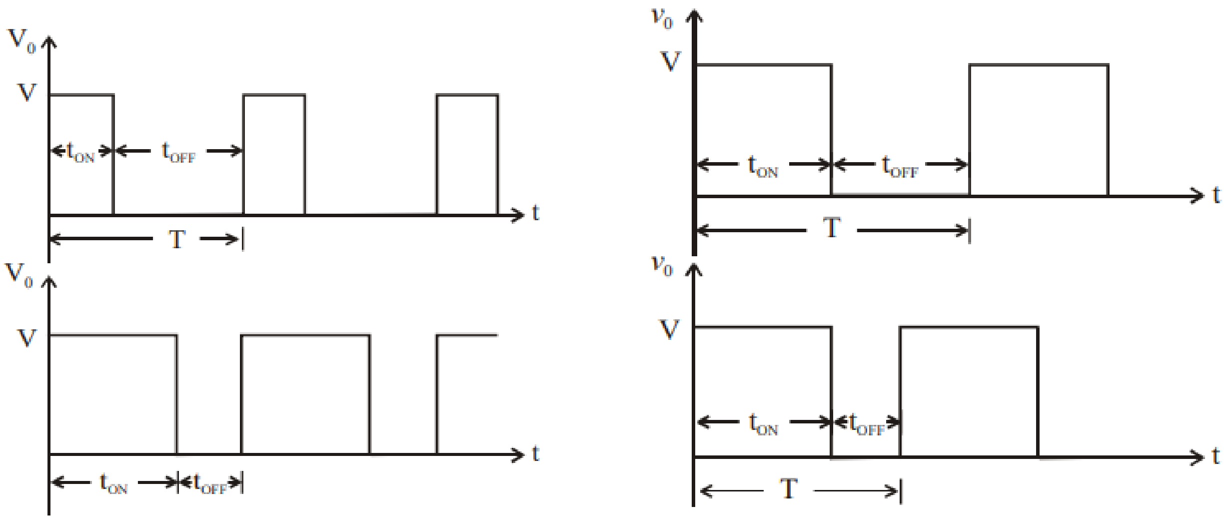
Therefore output power $P_O = \frac{V_O^2}{R}$

METHODS OF CONTROL:

- The output dc voltage can be varied by the following methods. Pulse width modulation control or constant frequency operation. Variable frequency control.

PULSE WIDTH MODULATION

- In pulse width modulation the pulse width of the output waveform is varied keeping chopping frequency ‘f’ and hence chopping period ‘T’ constant. Therefore output voltage is varied by varying the ON time.



VARIABLE FREQUENCY CONTROL

- In this method of control, chopping frequency f is varied keeping either or constant. This method is also known as frequency modulation.

- The output voltage waveforms for a constant and variable chopping period T. In frequency modulation to obtain full output voltage, range frequency has to be varied over a wide range. This method produces harmonics in the output and for large load current may become discontinuous.

Control Strategies of DC-DC conversion

- Time – Ratio Control:
- Constant Frequency Operation:
- Variable Frequency Operation:
- Current Limit Control:

Video Content / Details of website for further learning (if any):

https://www.pantechsolutions.net/blog/step-down-and-step-up-chopper/amp/

Important Books/Journals for further learning including the page nos.: 197-199

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LECTURE HANDOUTS

L21

EEE

III/V

Course Name with Code : 19EED07 / Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit III : DC to DC Choppers **Date of Lecture:**

Topic of Lecture: Switched Mode Regulators

Introduction :

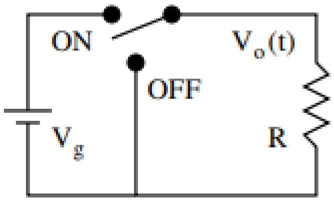
- The series controlled and the shunt-controlled regulators are commonly known as linear regulators. They are simple to analyze and design.
- The major drawback of linear regulators is their poor efficiency. The losses in such converters appear as heat in the series and shunt elements.
- The design of such converters must also take into account effective handling of the losses, so that the temperature rise of the components is within the safe limits.
- The linear regulators are therefore used only for low power levels, a few watts in the case of shunt regulators and a few tens of watts in the case of series regulators

Prerequisite knowledge for Complete understanding and learning of Topic:

- Converter

Detailed content of the Lecture:

- It was mentioned that the seed idea of switched mode power conversion came from the fact that the power dissipation in a series controlled regulator is zero at either end values of the control quantity Rc, namely Rc = 0 and Rc = ∞.
- The core of switched mode dc-to-dc converter is obtained by replacing the series pass element (Rc) of the series controlled regulator by a switch.



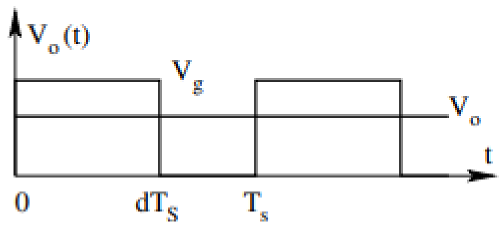
: Series Controlled Switching Regulator

- In the OFF position the output is totally isolated from the input. This is identical to the condition that Rc = ∞ in the series controlled regulator. In order to obtain a finite effective value of Rc, the switch is operated at high frequency alternating between these (ON and OFF) two states.

- The switch is operated at a switching period of Ts. For a fraction (dTs) of the switching period, the switch is kept ON. For the rest of the switching period [(1 − d)Ts], the switch is kept OFF.

- The fraction 'd' is defined as the duty ratio of the switch. The average output voltage under such a control is

$$V_o = \frac{1}{T_s} \int_0^{T_s} V_o(t)\, dt \;=\; d\, V_g$$



Output Voltage of the Switching Converter

- The duty ratio may be varied in the range of 0 to 1.The average value of the output voltage is therefore variable between 0 and Vg. There are no losses in the converter.
- The power dissipation in the switch is zero during both the ON and OFF states. Therefore the converter has ideally no losses. However the output voltage is not pure dc. The output apart from the desired average voltage (dVg), also has superimposed alternating voltage at switching frequency.
- Real dc-to-dc converters are required to provide nearly constant dc output voltage. A real dc-to-dc converter therefore consists of a low pass filter also apart from the switches.
- The function of the low pass filter is to pass the dc power to the load and to block the ac components at the switching frequency from reaching the output of the converter.
- In order to achieve efficient operation, the low pass filter is realized by means of non-dissipative passive elements such as inductors and capacitors.

Video Content / Details of website for further learning (if any):
http://www.onmyphd.com/?p=voltage.regulators.switching

Important Books/Journals for further learning including the page nos.: 201-203
P.S.Bimbra "Power Electronics" Khanna Publishers, third Edition, 2003.

Course Faculty

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LECTURE HANDOUTS

L22

EEE

III/V

Course Name with Code : 19EED07 / Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit III : DC to DC Choppers **Date of Lecture:**

Topic of Lecture: Buck and boost regulators

Introduction :

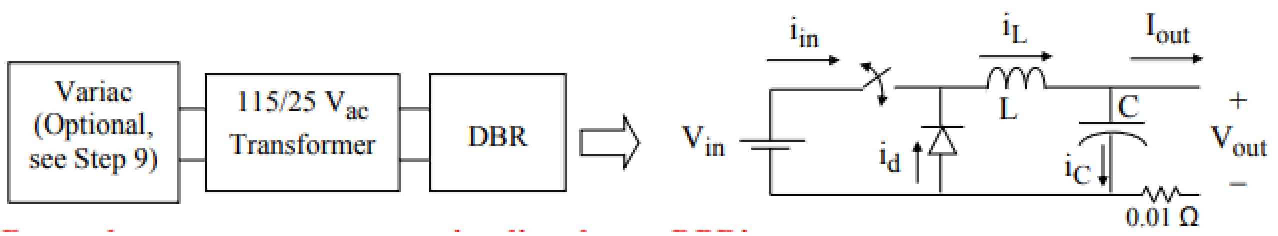
- DC-DC converters provide efficient conversion of dc voltage from one level to another.
- Specifically, the term "buck" converter means that the converter takes input from a higher voltage level, e.g. variable 36-42 Vdc from solar panels, and converts it to a lower voltage level, e.g. fixed 12 Vdc, for powering equipment.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Converters
- Electronic Switches

Buck regulators:

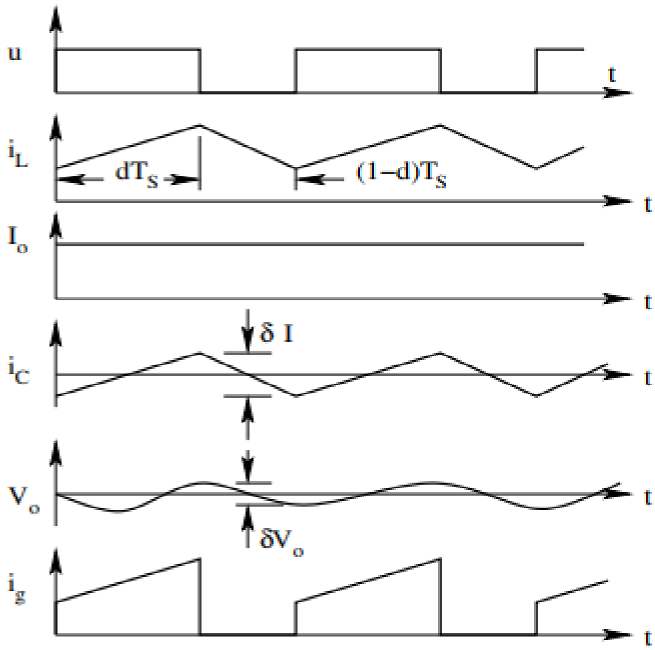
- Input voltage Vin is assumed to be ripple free. The power electronic switch opens and closes at a fixed rate of, for example, 100 kHz, and its duty cycle is varied to control Vout.
- Capacitor C is assumed to be large enough so that Vout has a ripple of less than 5% and is therefore, essentially ripple free. Iout is also assumed to be ripple free. In normal operation, the circuit is in "continuous conduction," e.g. iL is always greater than zero.



Buck Converter

The circuit is assumed to be lossless so that Pin = Pout,

$$V_{in} \cdot i_{in,avg} = V_{out} \cdot I_{out}$$



Steady State Waveforms of the Buck Converter

Voltage gain

Apply volt-sec balance on inductor:

Vo = dVg

Current ripple

$$\delta I_o = \frac{V_g d(1-d)T_S}{L} = \frac{V_o(1-d)T_S}{L}$$

$$\frac{\delta I_o}{I_o} = \delta_i = \frac{(1-d)RT_S}{L}$$

Voltage ripple

We consider that the ac part of the inductor current flows into the capacitor.

$$\delta V_o = \frac{\delta Q}{C} = \frac{1}{C}\frac{1}{2}\frac{\delta I_o}{2}\frac{T_S}{2}$$

$$\delta V_o = \frac{V_o(1-d)T_S^2}{8LC}$$

$$\frac{\delta V_o}{V_o} = \delta_v = \frac{(1-d)T_S^2}{8LC}$$

Input Current

The average of the source current is found as for the primitive converter.

Ig = dIo

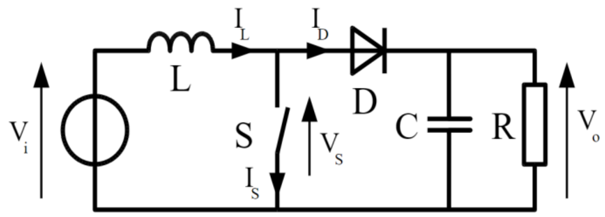
Validity of Results

The results are valid when

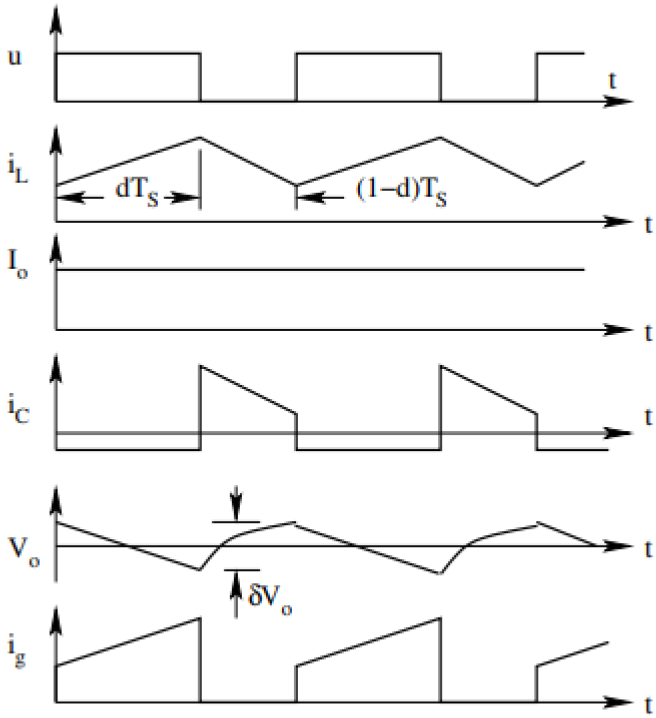
$$\frac{\delta V_o}{V_o} = \delta_v = \frac{5(1-d)T_S^2}{T_o^2} << 1$$

Boost regulators:

- Boost converter is a DC-to-DC power converter with an output voltage greater than its input voltage. It is a class of switched-mode power supply (SMPS) containing atleast two semiconductors (a diode and a transistor) and at least one energy storage element, a capacitor , inductor , or the two in combination. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.



Boost Converter



Steady State Waveforms of the Boost Converter

Voltage gain

Apply volt-sec balance on inductor.

$$V_o = \frac{V_g}{1-d}$$

When the parasitic resistance of the inductor (Rl) and the source resistance (Rg) are taken into account, the voltage gain gets degraded.

$$V_o = \frac{V_g}{1-d}\left\{\frac{1}{1+\frac{\alpha}{(1-d)^2}}\right\}\ ;\ \alpha = \frac{R_l + R_g}{R}$$

Current Ripple

In each sub-period [dTS and (1−d)TS] the rate of change of current is constant.

$$\delta I_L = \frac{V_g d T_S}{L}$$

$$\frac{\delta I_L}{I_L} = \delta_i = \frac{d(1-d)^2 R T_S}{L}$$

Voltage Ripple

The charging and discharging current of the capacitor decides voltage ripple. We consider that the entire ac part of the inductor current flows into the capacitor.

$$\delta V_o = \frac{\delta Q}{C} = \frac{I_o d T_S}{C}$$

$$\frac{\delta V_o}{V_o} = \delta_v = \frac{d T_S}{RC}$$

Input Current

The average of the inductor current is the same as the average source current.

$$I_g = \frac{I_o}{1-d}$$

Validity of Results

The results are valid when

$$\frac{\delta V_o}{V_o} = \delta_v = \frac{d T_S}{RC} << 1$$

Video Content / Details of website for further learning (if any):
https://www.analog.com/en/products/power-management/switching-regulators/buck-boost-regulators.html

Important Books/Journals for further learning including the page nos.: 204-206
P.S.Bimbra "Power Electronics" Khanna Publishers, third Edition, 2003.

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L23

LECTURE HANDOUTS

EEE

III/V

Course Name with Code : 19EED07 / Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit III : DC to DC Choppers **Date of Lecture:**

Topic of Lecture: Buck boost converter

Introduction :

- The buck boost converter is a type of DC-to-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. It is equivalent to a flyback converter using a single inductor instead of a transformer.
- Two different topologies are called buck–boost converter. Both of them can produce a range of output voltages, ranging from much larger (in absolute magnitude) than the input voltage, down to almost zero.

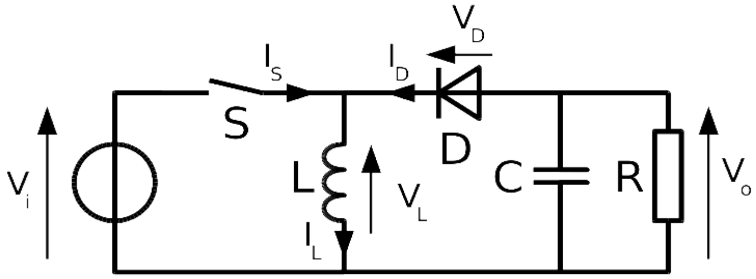
Prerequisite knowledge for Complete understanding and learning of Topic:

- Flyback converter

Detailed content of the Lecture:

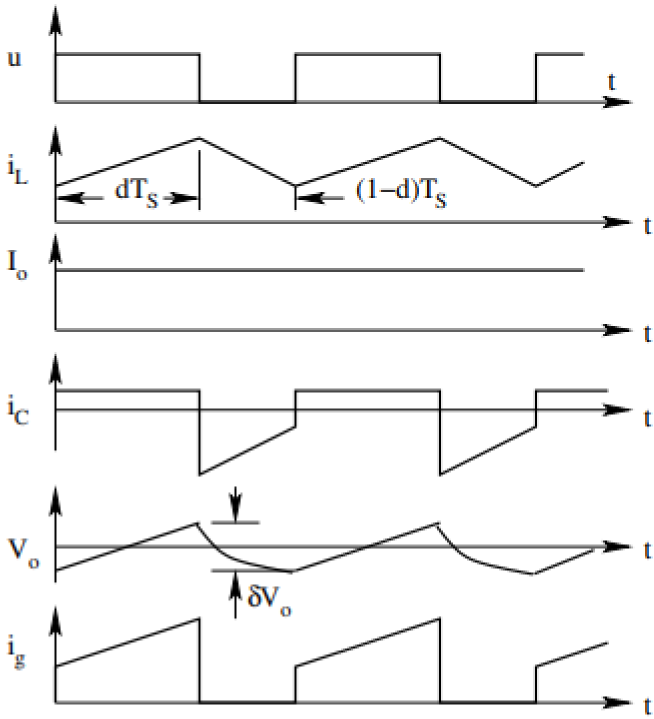
Buck boost converter:

- While in the On-state, the input voltage source is directly connected to the inductor (L). This results in accumulating energy in L. In this stage, the capacitor supplies energy to the output load.
- While in the Off-state, the inductor is connected to the output load and capacitor, so energy is transferred from L to C and R.
- Compared to the buck and boost converters, the characteristics of the inverting buck–boost converter are mainly polarity of the output voltage is opposite to that of the input.
- Like the buck and boost converters, the operation of the buck-boost is best understood in terms of the inductor's "reluctance" to allow rapid change in current. From the initial state in which nothing is charged and the switch is open, the current through the inductor is zero.
- When the switch is first closed, the blocking diode prevents current from flowing into the right hand side of the circuit, so it must all flow through the inductor. However, since the inductor doesn't allow rapid current change, it will initially keep the current low by dropping most of the voltage provided by the source.
- Over time, the inductor will allow the current to slowly increase by decreasing its voltage drop. Also during this time, the inductor will store energy in the form of a magnetic field.



Schematic of a buck–boost converter.

- If the current through the inductor L never falls to zero during a commutation cycle, the converter is said to operate in continuous mode. The current and voltage waveforms in an ideal converter.



Steady State Waveforms of the Buck Boost Converter

Voltage Gain

Apply volt-sec balance on inductor

$$V_o = -\frac{dV_g}{1-d}$$

When the parasitic resistance of the inductor Rl and the source resistance Rg are taken into account, the voltage gain gets degraded.

$$V_o = \frac{V_g}{1-d}\left\{\frac{1}{1+\frac{\alpha+\beta d}{(1-d)^2}}\right\};\ \alpha = \frac{R_l}{R}; \beta = \frac{R_g}{R}$$

Current Ripple

In each sub period [dTS and (1−d)TS] the rate of change of current is constant.

$$\delta I_L = \frac{V_g d T_S}{L}$$

$$\frac{\delta I_L}{I_L} = \delta_i = \frac{(1-d)^2 R T_S}{L}$$

Voltage Ripple

The charging and discharging current of the capacitor) decides the voltage ripple. We consider that the entire ac part of the inductor current flows into the capacitor.

$$\delta V_o = \frac{\delta Q}{C} = \frac{I_o d T_S}{C}$$

$$\frac{\delta V_o}{V_o} = \delta_v = \frac{d T_S}{RC}$$

Input Current

The average source current may be obtained from the average inductor current.

$$I_g = \frac{d I_o}{1-d}$$

Validity of Results

The results are valid when

$$\frac{\delta V_o}{V_o} = \delta_v = \frac{d T_S}{RC} << 1$$

Video Content / Details of website for further learning (if any):

https://www.sciencedirect.com/topics/engineering/cuk-converter

Important Books/Journals for further learning including the page nos.: 207-212

P.S.Bimbra “Power Electronics” Khanna Publishers, third Edition, 2003.

Course Faculty

LECTURE HANDOUTS

L24

EEE

III/VI

Course Name with Code : 19EED07 / Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit III : DC to DC Choppers **Date of Lecture:**

Topic of Lecture: Operation of two quadrant and four quadrant DC choppers with R and RL load (Chopper classifications)

Introduction :

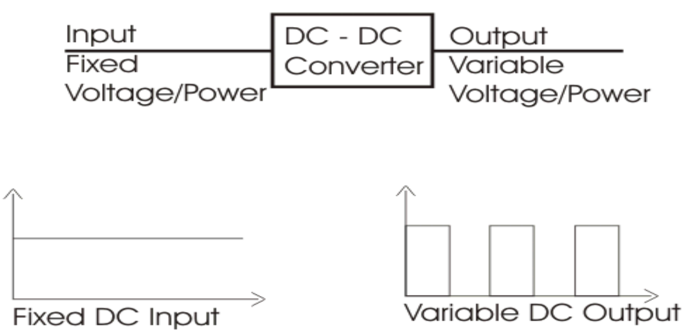
- DC to DC converter is very much needed nowadays as many industrial applications are dependent upon DC voltage source.
- The performance of these applications will be improved if we use a variable DC supply. It will help to improve controllability of the equipments also.
- Examples of such applications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

Prerequisite knowledge for Complete understanding and learning of Topic:

- Converters
- Semiconductor Devices

Chopper classifications

- Chopper is a basically static power electronics device which converts fixed DC voltage/power to variable DC voltage or power



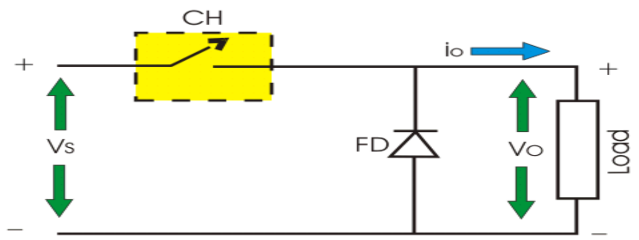
- It is nothing but a high speed switch which connects and disconnects the load from source at a high rate to get variable or chopped voltage at the output.
- Chopper can increase or decrease the DC voltage level at its opposite side. So, chopper serves the same purpose in DC circuit transfers in case of ac circuit. So it is also known as DC transformer.

Devices used in Chopper

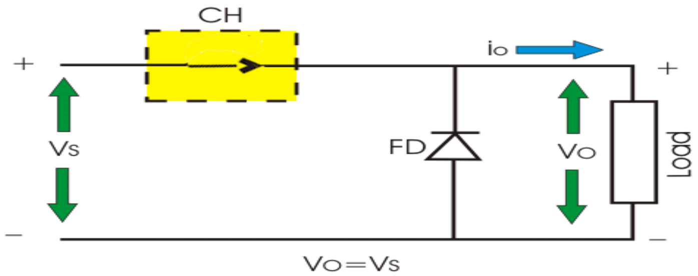
- Low power application: GTO, IGBT, Power BJT, Power MOSFET etc.
- High power application: Thyristor or SCR.
- These devices are represented as a switch in a dotted box for simplicity. When it is closed current can flow in the direction of arrow only.

Step down Chopper :

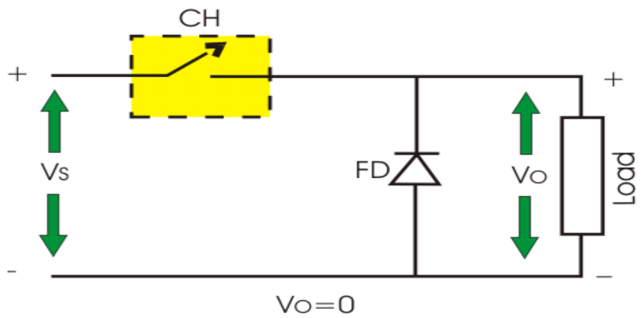
Step down chopper as Buck converted is used to reduce the i/p voltage level at the output side. Circuit diagram of a step down chopper is shown in the adjacent figure.



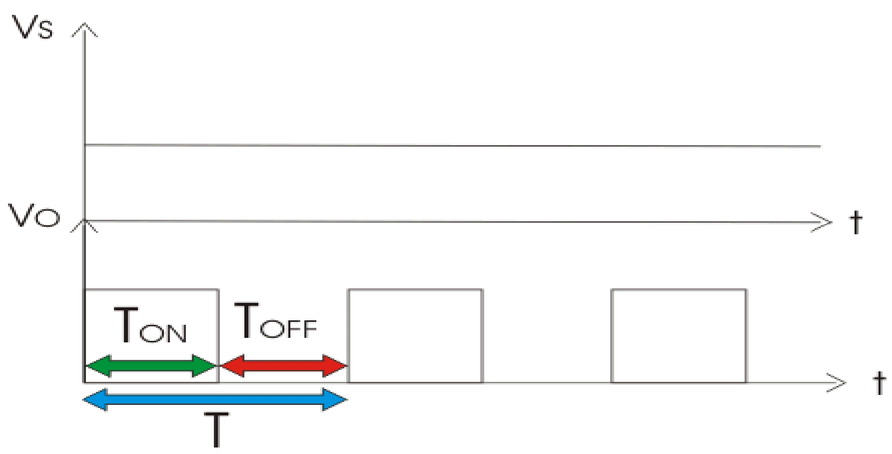
1) When CH is turned ON, V_s directly appears across the load as shown in figure. So $V_o = V_S$.



2) When CH is turned off, V_s is disconnected from the load. So output voltage $V_o = 0$.



The voltage waveform of step down chopper is shown below:

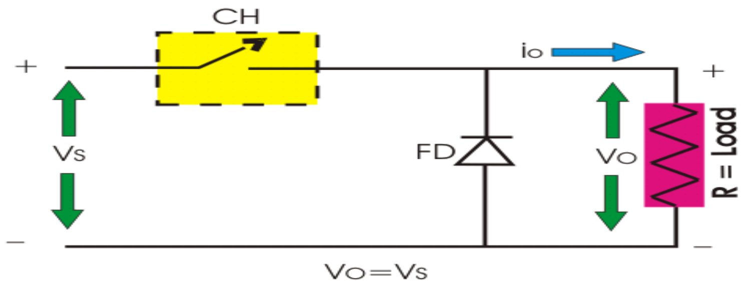


T_{ON} → It is the interval in which chopper is in ON state.
T_{OFF} → It is the interval in which chopper is in OFF state.
V_S → Source or input voltage.

$V_o \rightarrow$ Output or load voltage.
$T \rightarrow$ Chopping period = $T_{ON} + T_{OFF}$

Operation of Step Down Chopper with Resistive Load

When CH is ON, $V_o = V_S$
When CH is OFF, $V_o = 0$



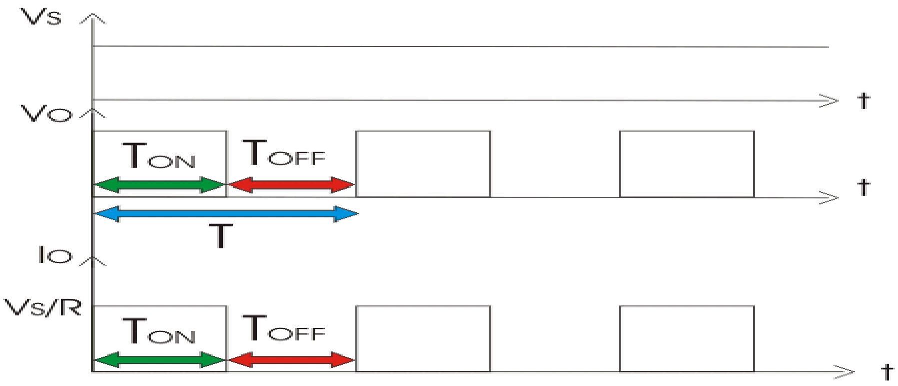
$$Average\ output\ voltage\ V_O = \frac{1}{T}\int_0^{T_{ON}} V_s dt = \frac{V_s T_{ON}}{T} = DV_s$$

Where, D is duty cycle = T_{ON}/T.
T_{ON} can be varied from 0 to T, so $0 \le D \le 1$. Hence output voltage V_o can be varied from 0 to V_S.

$$RMS\ output\ voltage\ V_{or} = \sqrt{\frac{1}{T}\int_0^{T_{ON}} V_s^2 dt} = V_s\sqrt{\frac{T_{ON}}{T}} = \sqrt{D}V_s$$

$$Therefore, Effective\ input\ resistance\ R_i = \frac{V_s}{T_{savg}} = \frac{V_s}{DV_s/R} = \frac{R}{D}$$

So, we can conclude that output voltage is always less than the input voltage and hence the name step down chopper is justified. The output voltage and current waveform of step down chopper with resistive load is shown below.



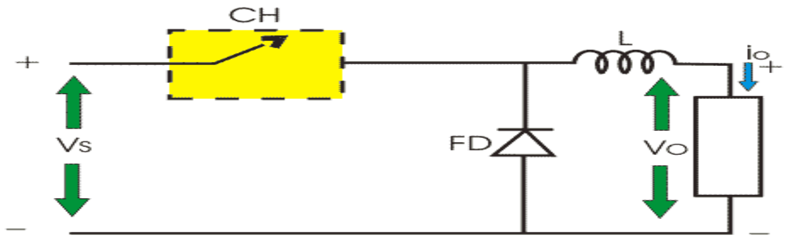
Operation Of Step Down Chopper with Inductive Load

When CH is ON, $V_o = V_S$
When CH is OFF, $V_o = 0$
During ON time of Chopper

$$V_s = V_L + V_o \Rightarrow V_L = V_s - V_o \Rightarrow L\frac{di}{dt} = V_s - V_o \Rightarrow L\frac{\Delta I}{T_{ON}} = V_s - V_o$$

Therefore, peak to peak load current,

$$\Delta I = \frac{V_s - V_o}{L} T_{ON} \cdots\cdots\cdots (i)$$



During OFF Time of Chopper

If inductance value of L is very large, so load current will be continuous in nature. When CH is OFF inductor reverses its polarity and discharges. This current freewheels through diode FD.

$$Therefore,\ L\frac{di}{dt} = V_o$$

$$L\frac{\Delta I}{T_{OFF}} = V_o \Rightarrow \Delta I = V_o \frac{T_{OFF}}{L} \cdots\cdots\cdots (ii)$$

By equating (i) and (ii)

$$\frac{V_s - V_o}{L} T_{ON} = \frac{V_o}{L} T_{OFF}$$

$$\frac{V_s - V_o}{V_o} = \frac{T_{OFF}}{T_{ON}}$$

$$\frac{V_s}{V_o} = \frac{T_{ON} - T_{OFF}}{T_{ON}}$$

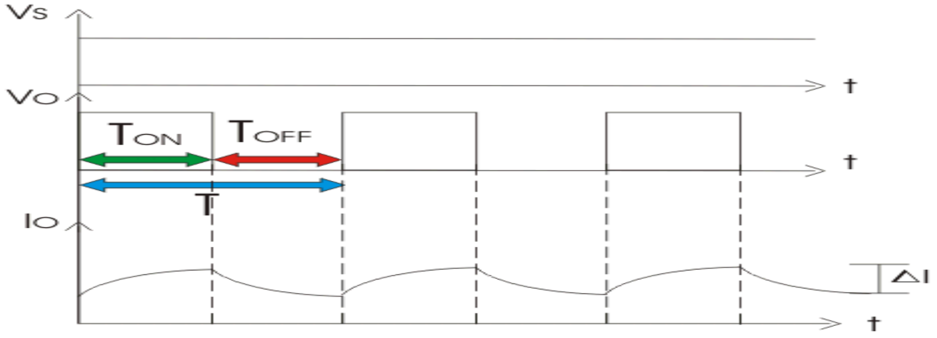
$$Therefore,\ V_o = \frac{T_{ON}}{T} V_s = DV_s$$

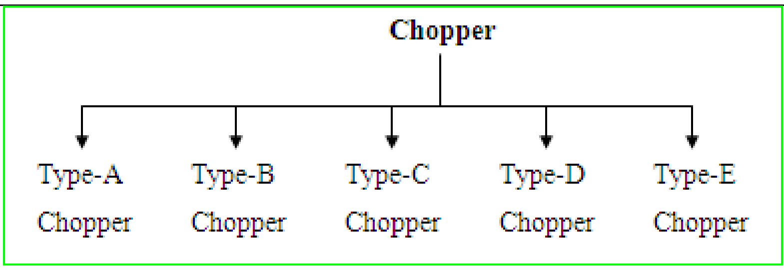
So, from (i) we get,

$$\Delta I = \frac{V_s - DV_s}{L} DT \left[Since,\ D = \frac{T_{ON}}{T}\right]$$

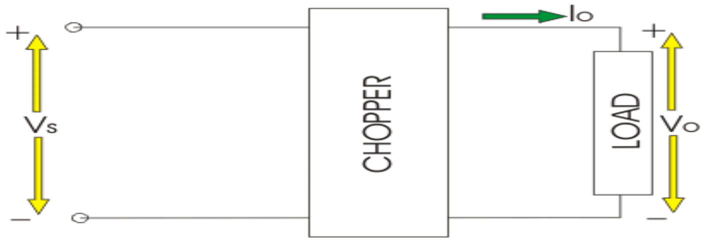
$$= \frac{V_s(1-D)D}{Lf} \left[f = \frac{1}{T} = Chopping\ Frequency\right]$$

The output voltage and current waveform of step down chopper with inductive load is shown below

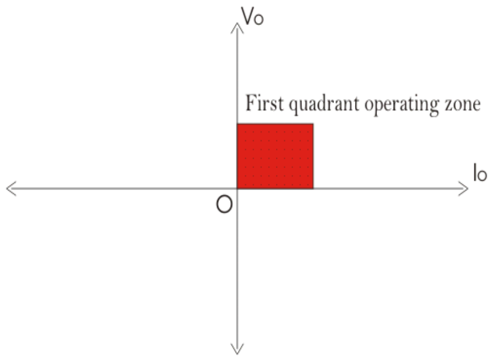


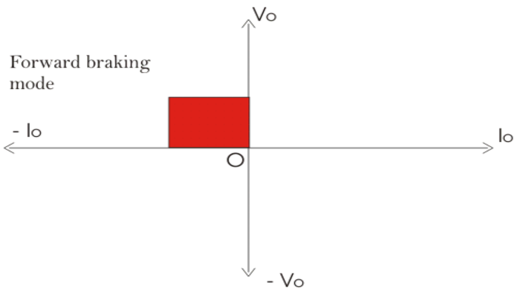


Before detailed analysis some basic idea regarding V_o – I_o quadrant is required here. The directions of I_o and V_o marked in the figure is taken as positive direction.



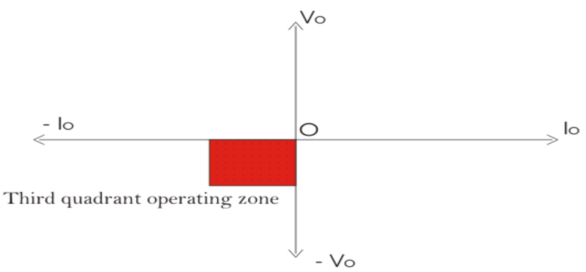
If output voltage (V_o) and output current (I_o) follows the direction as marked in figures then the chopper operation will be restricted in the first quadrant of $V_o – I_o$ plane. This type of operation is also known as forward motoring.

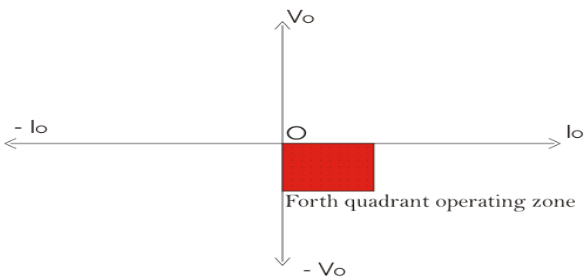




When output voltage (V_o) follows the marked direction in fig. 1 but current flows in the opposite direction then V_o is taken positive but I_o as negative. Hence the chopper operates in the second quadrant of $V_o – I_o$ plane. This type of operation is also known as forward braking.

It may also happen that both output voltage and current is opposite to the marked direction in figure – 1. In t his case both V_o and I_o are taken as negative. Hence chopper operation is restricted in third quadrant of V_o-I_o plane. This operation is called reverse motoring.





If output voltage is opposite to the marked direction in fig. 1. then it is taken as negative. But output current follows the direction as marked in fig. 1 and considered as positive. Hence chopper operates in 4th quadrant of $V_o - I_o$ plane. This mode of operation is called reverse braking.

Now we can proceed to detailed analysis of different types of chopper. Some choppers operate in a single quadrant only, which are called single quadrant chopper. Some choppers operate in two quadrant also which are known as two quadrant chopper. It is also possible that a chopper operates in all the quadrants, which are known as 4-quadrant chopper.

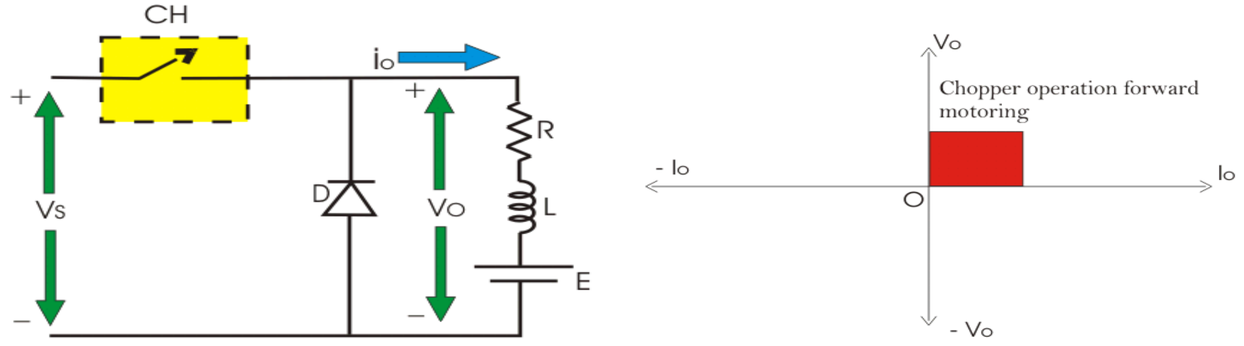
Type-A Chopper

It is a single quadrant chopper whose operation is restricted in first quadrant of $V_o - I_o$ plane. The circuit diagram is shown as below :

When CH is ON both V_o and I_o follows the direction as marked in the figures. So, both are taken as positive hence load power is positive which means power is delivered from source to land.

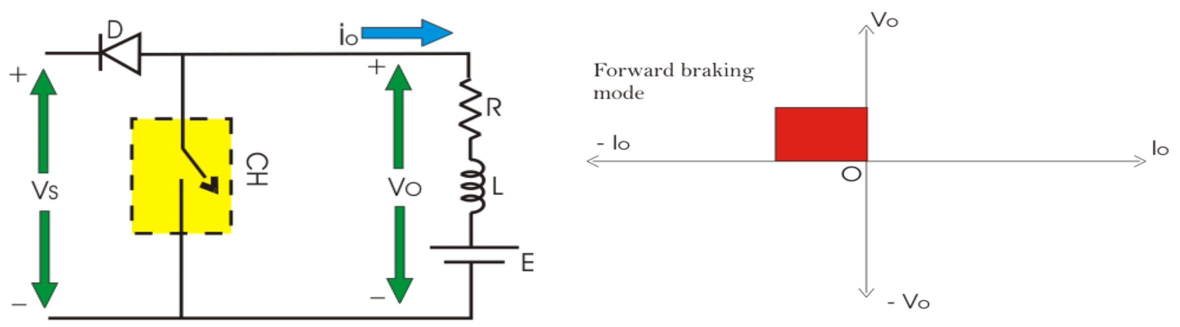
When CH is OFF current freewheels through diode. Hence V_o is zero and I_o is positive.

In type-A chopper it is seen that average value of V_o and I_o is always positive. This is also called step down chopper as average value of V_o is less than the input voltage. This type of chopper is suitable for motoring operation.



Type-B Chopper

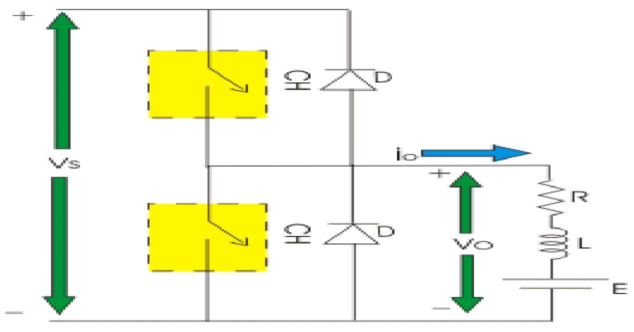
This is also a single quadrant chopper operating in second quadrant of $V_o - I_o$ plane. The circuit diagram is shown in the following figure.

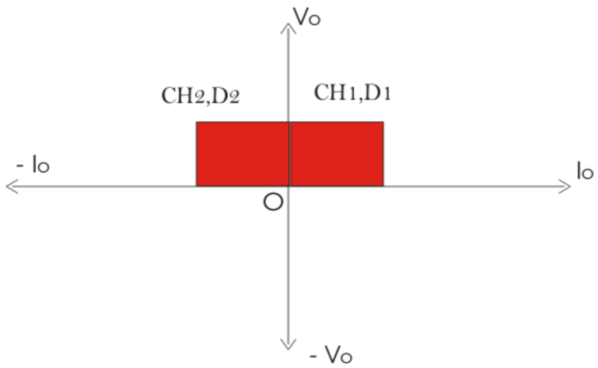


It is interesting to note that load must have a DC voltage source E for this kind of operation. When CH is ON V_o is zero but current flows in the opposite direction as marked in figure. When chopper is OFF. Which exceeds the source voltage V_S. So current flows through diode D and treated as negative. Hence current I_o is always negative here but V_o is positive (sometimes zero).

Type-C Chopper

This is a two quadrant chopper whose operation is bounded between first and second quadrant of $V_o - I_o$ plane. This type of chopper obtained by connecting type-A and type-B chopper in parallel as shown in the figure.





Hence output voltage V_o and current I_o both will be positive. When CH_1 is OFF, induction will discharge through D_1 and current I_o will flow through same direction with zero output voltage. When CH_2 is ON, output voltage V_o will be zero but output current I_o will flow in opposite direction of current shown in the figure and inductor will be charged up. When CH_2 is OFF Output voltage.

$$V_O = \left[E + L\frac{di}{dt} - IR\right]$$

Video Content / Details of website for further learning (if any):
https://www.circuitstoday.com/types-of-chopper-circuits

Important Books/Journals for further learning including the page nos.: 213-218
P.S.Bimbra "Power Electronics" Khanna Publishers, third Edition, 2003.

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

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(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
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L25

LECTURE HANDOUTS

EEE **III/V**

Course Name with Code : 19EED07 / Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit III : DC to DC Choppers **Date of Lecture:**

Topic of Lecture: Voltage commutated chopper

Introduction :

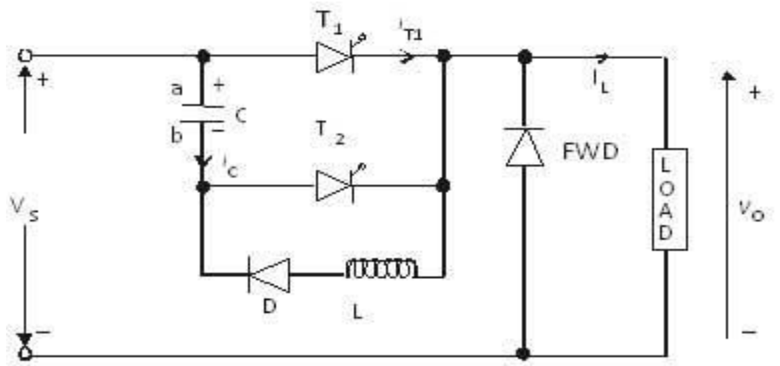
- In a voltage commutated thyristor circuit a voltage source is impressed across the SCR to be turned off, mostly by an auxiliary SCR. This voltage is comparable in magnitude to the operating voltages. The current in the conducting SCR is immediately quenched; however the reverse-biasing voltage must be maintained for a period greater than that required for the device to turn-off.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Switching Devices
- Triggering

Voltage commutated chopper :

- In a voltage commutated thyristor circuit a voltage source is impressed across the **SCR** to be turned off, mostly by an auxiliary **SCR** . This voltage is comparable in magnitude to the operating voltages.
- The current in the conducting **SCR** is immediately quenched, however the reverse-biasing voltage must be maintained for a period greater than that required for the device to turn-off.
- With a large reverse voltage turning it off, the device offers the fastest turn-off time obtainable from that particular device. It is an exposition of 'hard' turn-off where the reverse biasing stress is maximum.

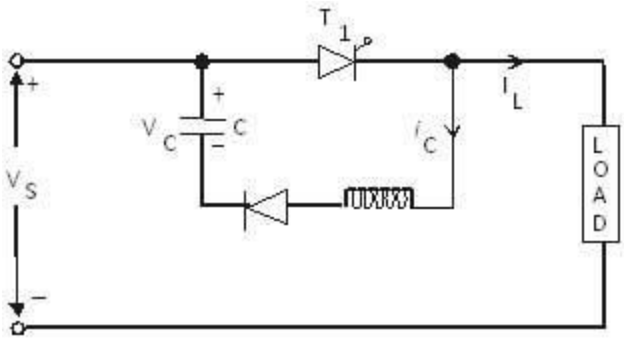


Load Connected a resistive load 50 ohms/2A or 100ohms/2A rheostat at load terminals A & B.

Working Principle

For convenience the chopper operation is divided into five modes.Mode-1, Mode-2, Mode-3, Mode-4 and Mode-5

Mode-1 Operation



Capacitor Discharge Current

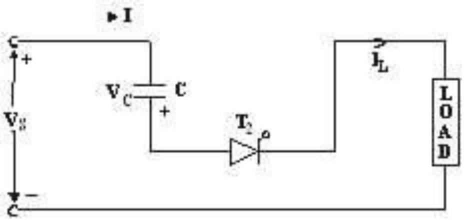
$$i_c(t) = V\sqrt{\frac{C}{L}}\sin \omega t$$

Where $\omega = \frac{1}{\sqrt{LC}}$

& Capacitor Voltage

- Thyristor T1 is fired at t = 0.The supply voltage comes across the load.
- Load current IL flows through T1 and load.
- At the same time capacitor discharges through T1, D1, L1, & 'C' and the capacitor reverses its voltage.
- This reverse voltage on capacitor is held constant by diode D1.

Mode-2 Operation



- Thyristor T2 is now fired to commutate thyristor T1.
- When T2 is ON capacitor voltage reverse biases T1 and turns if off.
- The capacitor discharges through the load from –V to 0.
- Discharge time is known as circuit turn-off time.
- Capacitor recharges back to the supply voltage (with plate 'a' positive).

This time is called the recharging time and is given by The total time required for the capacitor to discharge and recharge is called the commutation time and it is given by

$$t_d = \frac{V_S \times C}{I_L} \qquad t_r = t_C + t_d$$

At the end of Mode-2 capacitor has recharged to VS and the freewheeling diode starts conducting.

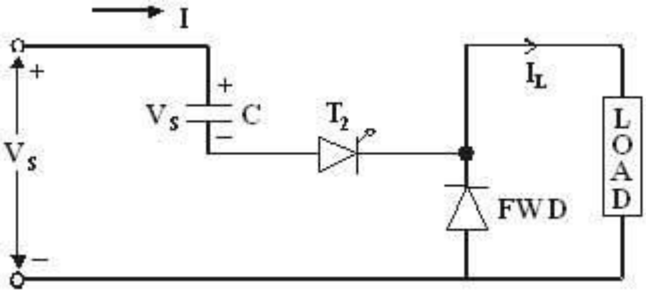
Circuit turn-off time is given by

$$t_C = \frac{V_C \times C}{I_L}$$

Where I_L is load current.

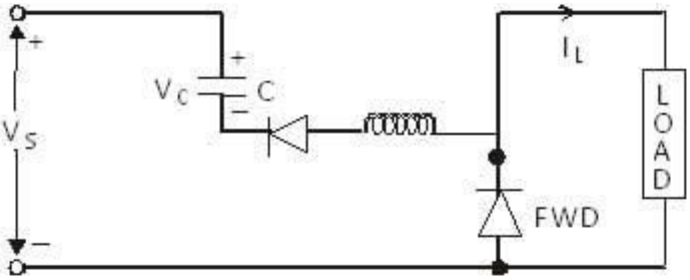
t_C depends on load current, it must be designed for the worst case condition which occur at the maximum value of load current and minimum value of capacitor voltage.

Mode-3 Operation



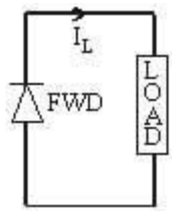
- FWD starts conducting and the load current decays.
- Hence capacitor charges to a voltage higher than supply voltage, T2 naturally turns off.

Mode-4 Operation



- Capacitor has been overcharged i.e. its voltage is above supply voltage.
- Capacitor starts discharging in reverse direction.
- Hence capacitor current becomes negative.
- The capacitor discharges through VS, FWD, D1 and L.
- When this current reduces to zero D1 will stop conducting and the capacitor voltage will be same as the supply voltage

Mode-5 Operation



Both thyristors are off and the load current flows through the FWD. This mode will end once thyristor T1 is fired.

Video Content / Details of website for further learning (if any):
http://engineeringwrittennotes.blogspot.com/2016/07/voltage-commutated-chopper-voltage.html?m=1

Important Books/Journals for further learning including the page nos.: 219-224
P.S.Bimbra "Power Electronics" Khanna Publishers, third Edition, 2003.

Course Faculty

L26

LECTURE HANDOUTS

EEE | **III/VI**

Course Name with Code : 19EED07 / Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit III : DC to DC Choppers **Date of Lecture:**

Topic of Lecture: Current commuted chopper

Introduction :

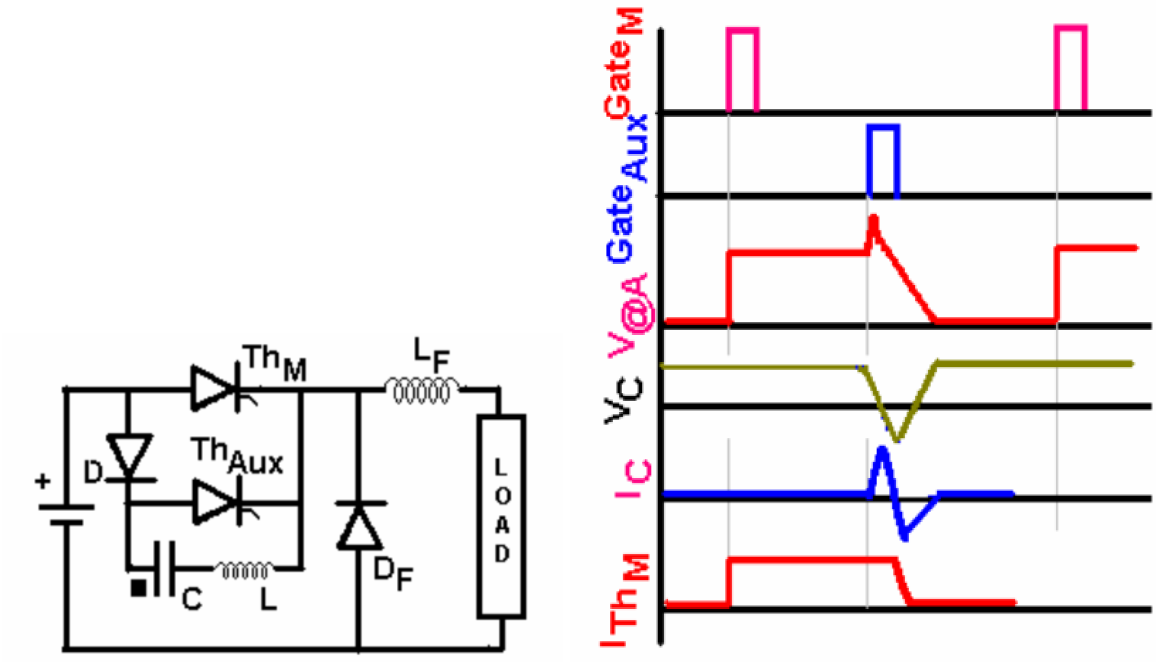
- A commutator is a rotary electrical switch in certain types of electric motors and electrical generators that periodically reverses the current direction between the rotor and the external circuit.
- It consists of a cylinder composed of multiple metal contact segments on the rotating armature of the machine.
- Two or more electrical contacts called "brushes" made of a soft conductive material like carbon press against the commutator, making sliding contact with successive segments.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Switching Device
- Triggering

Current commuted chopper :

- The circuit of Figure can be converted into a current commuted one just by interchanging the positions of the diode and the capacitor. Here the Capacitor is automatically charged through D-L-LF-Load with the dot as positive. Any of the SCRs can thus be switched on first.
- If ThM is triggered first, it immediately takes the load current turning off DF. When ThAux is triggered, it takes a half cycle of the ringing current in the L-C circuit and the polarity of the charge across the capacitor reverses.
- As it swings back, ThAux is turned off and the path through D-C-L shares the load current which may again be considered to be reasonably level. The Current-share of THM is thus reduced in a sinusoidal (damped) manner.
- Turn-off process is consequently accompanied by an overlap between ThM and the diode D in the D-C-L path. Once the main SCR is turned off, the capacitor current becomes level and the voltage decreases linearly.



- A voltage spike appears across the load when the voltage across the commutating inductance collapses and the capacitance voltage adds to the supply voltage. Figure.
- A current commutated DC-DC Chopper and most significant waveforms The free-wheeling diode also turns on through a overlap with D when the capacitor voltage just exceeds the supply voltage and this extra voltage drives the commutating current through the path D-Supply-DF-L. Thus there is soft switching of all devices during this period.
- Further an additional diode may be connected across the main SCR. It ensures ‘soft’ turnoff by conducting the excess current in the ringing L-C circuit. The low forward voltage appearing across the SCR causes it to turn-off slowly. Consequently switching frequencies have to be low. Note that such a diode cannot be connected across the Main SCR in the voltage commutated circuit.

Video Content / Details of website for further learning (if any):
https://studylib.net/doc/18143238/voltage-current-and-load-commutated

Important Books/Journals for further learning including the page nos.: 225-227
P.S.Bimbra “Power Electronics” Khanna Publishers, third Edition, 2003.

Course Faculty

LECTURE HANDOUTS

L26

EEE | **III/VI**

Course Name with Code : 19EED07 / Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit III : DC to DC Choppers **Date of Lecture:**

Topic of Lecture: Load commuted chopper

Introduction :

- A commutator is a rotary electrical switch in certain types of electric motors and electrical generators that periodically reverses the current direction between the rotor and the external circuit.
- It consists of a cylinder composed of multiple metal contact segments on the rotating armature of the machine.
- Two or more electrical contacts called "brushes" made of a soft conductive material like carbon press against the commutator, making sliding contact with successive segments.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Switching Device
- Triggering

Load commuted chopper :

- This chopper circuit consist of four thyristors T_1 ,T_2 ,T_3 ,T_4 and one commutating Capacitor C.Here,thyristors T_1 ,T_2 T1,T2 from one pair and thyristors T_3 ,T_4 form another pair which conduct the load current alternatively.
- When one thyristor pair T_1 ,$T2$ functions as main thyristors,at the same time other thyristor pair T_3 ,T_4 functions auxillary thyristors,and vice-versa.
- Again,operation of the chopper circuit is divided into different modes.These modes are described with associated waveforms as shown in fig.

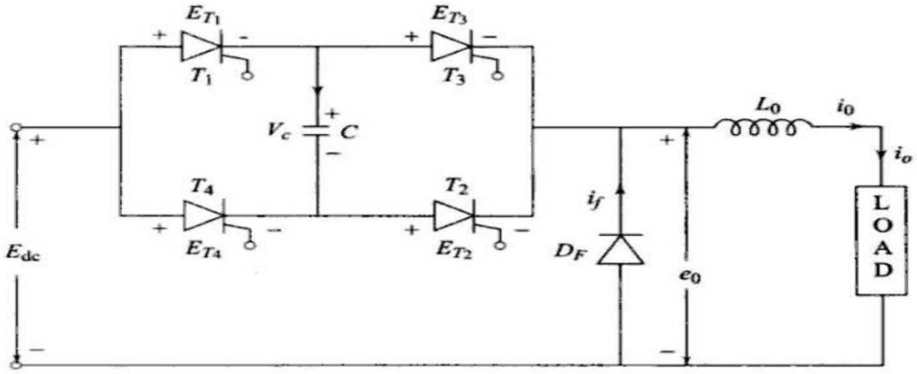


Fig.1 Load commutated chopper circuit

- The waveforms shown in Fig. starts at the instant $t=t_0$. It is assumed that prior to this instant t_0, capacitor C was charged to the reverse voltage ($-E_{dc}$) due to the conduction of thyristors T_3 and T_4.
- Therefore, before the instant t_0, the capacitor upper plate becomes negative and lower plate positive.

Mode 1 Operation:

- As shown in Fig.2 at $t=t_0$ both thyristors T_1 and T_2 are triggered. Therefore, load current flows through the path $E_{dc} - T_1, C, T_2$ and the load.
- Load voltage e_0 now becomes, $e_0 = E_{dc} - V_c$, i.e., $2E_{dc}$. The capacitor C is charged linearly by a constant load current i_0 from ($-E_{dc}$) at $t=0$ to E_{dc} at t_1.
- When the capacitor is charged fully positive at $t=t_1$,the current through the conducting thyristors T_1, T_2 becomes zero and these go into the blocking mode.
- The load voltage e_0 falls linearly. The freewheeling diode D_f becomes forward biased, and the load current is transferred from T_1 and T_2 to D_f

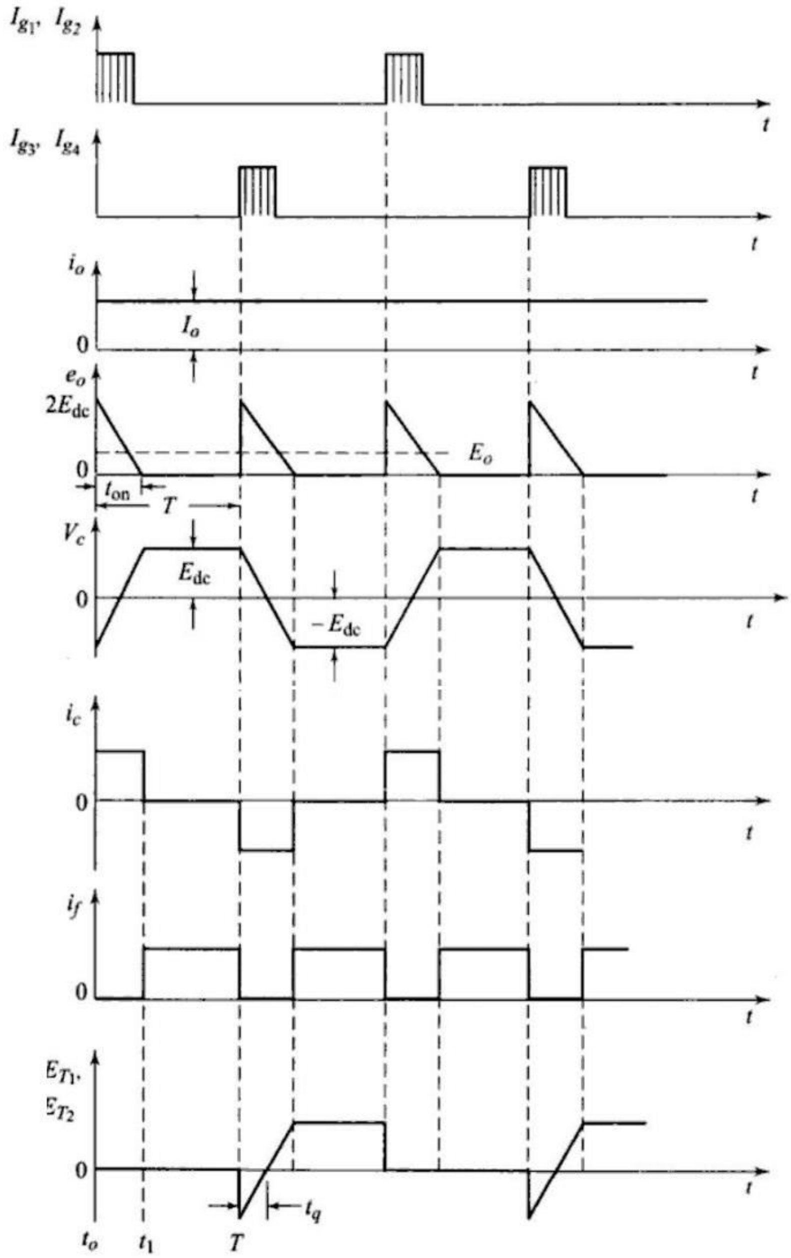


Fig.2 *Voltage and current waveforms of load-commutated chopper*

Mode 2 Operation:

- As shown in Fig. from t_1 to T, the freewheeling diode D_F conducts the load current. For the period t_1 to $T, V_c = E_{dc}, i_c = 0, i_f = i_0$ and the load voltage $e_0 = 0$.
- Now, at $t=T$, the second pair of thyristors T_3, T_4 is triggered.
- This places the fully charged capacitor across thyristors T_1 T_2, reverse biasing them and turning them off. The cycle now repeats.

Advantage:

1.This chopper is capable of commutating any amount of current.

2.No commutating inductor is required in this chopper circuit which is normally costly, bulky and noisy.

3.This circuit can operate at high frequencies of the order of kHz , and therefore filtering requirements to smooth out load current are minimal.

Disadvantage:

1.The peak load voltage is twice the supply voltage. However, this peak can be reduced by filtering.

2.Because of higher switching losses at high frequencies and losses in the two conducting thyristors in series with the load, efficiency may become low for high power applications.

3.Since freewheeling diode D_f is subjected to twice the supply voltage($2E_{dc}$) in a short time, a fast recovery type diode must be used.

4.The commutating capacitor has to carry the load current at a frequency half the chopping period.

5.One thyristor pair should be turned-on only when the other pair is commutated. This can be realised by sensing the capacitor current that is alternating.

Video Content / Details of website for further learning (if any):
https://studylib.net/doc/18143238/voltage-current-and-load-commutated

Important Books/Journals for further learning including the page nos.: 225-227
P.S.Bimbra “Power Electronics” Khanna Publishers, third Edition, 2003.

Course Faculty

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L28

LECTURE HANDOUTS

EEE | **III / V**

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit IV : DC - AC Converters **Date of Lecture:**

Topic of Lecture:

Principles of inverter operation

Introduction :

- **A**n inverter is used to produce an un-interrupted 220V AC or 110V AC (depending on the line voltage of the particular country) supply to the device connected as the load at the output socket. The inverter gives constant AC voltage at its output socket when the AC mains power supply is not available.

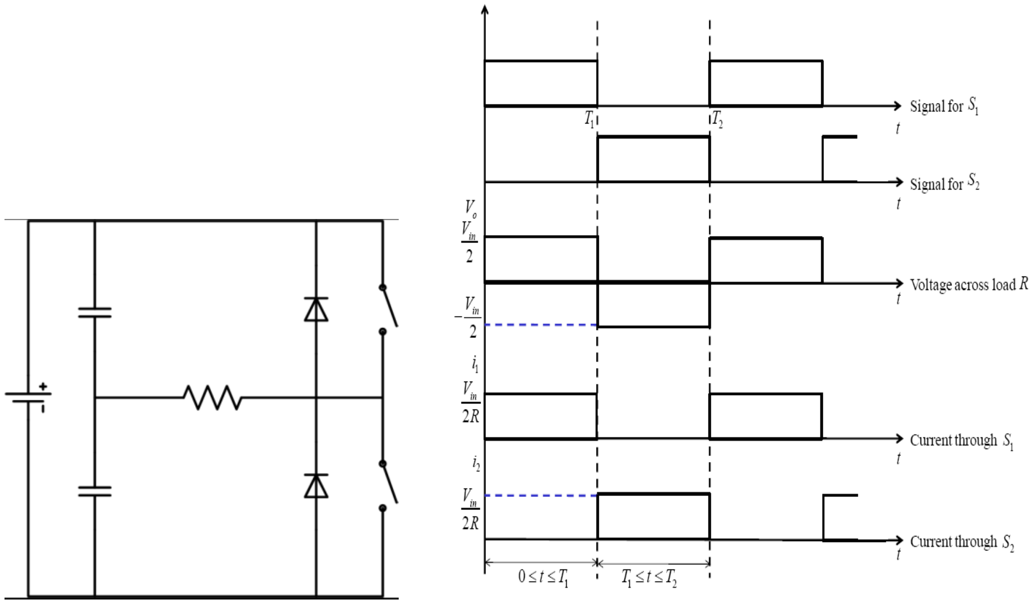
Prerequisite knowledge for Complete understanding and learning of Topic:

- Rectifier
- Basic of battery operation

Principles of inverter operation

- ✓ Inverters can broadly be classified into Voltage Source (VSI) and Current Source Inverters (CSI). Voltage source inverters are supplied from ideal (or low impedance) DC voltage sources. The DC source can be fixed or variable, with very low source impedance. With such a source, the output
- ✓ AC voltage is determined completely by the DC source voltage and the states of the switching devices in the inverter. This of course assumes that the load current does not become discontinuous. The DC source may be in the form of batteries, generators, solar cells or for large power applications, controlled or uncontrolled AC-DC rectifier circuits terminated with a C- or LC-filter which offers low impedance path to the lagging components of the load current which must sink into the DC source.
- ✓ The function of an inverter is to change a dc input voltage to a symmetric ac output voltage of desired magnitude and frequency. The output voltage waveforms of ideal inverters should be sinusoidal. However, the waveforms of practical inverters are non-sinusoidal and contain certain harmonics.
- ✓ A single phase inverter is shown in Figure . The analysis of the DC-AC inverters is done taking into account the following assumptions and conventions: The current entering node a in Figure is considered to be positive.
- ✓ The switches S1 and S2 are unidirectional, i.e. they conduct current in one direction. The current through S1 is denoted as i_1 and the current through S2 is i2 .

- ✓ The switching sequence is so design (Figure) that switch S1 is on for the time duration t T≤ ≤1 0 and the switch 2 S is on for the time duration . When switch≤ <T t T 1 2 1 S is turned on, the instantaneous voltage across the load is V0 = Vin/2
- ✓ For resistive load the load voltage and load current Io are inphase with each other. For inductive load the load current will not be inphase with load voltage. The diode D1 and D2 which are connected anti-parallel with the thyristors carries current when the thyristors are turned off
- ✓ For inverter circuits, the output voltage and current waveforms, vo and io respectively, are assumed to be AC quantities. These are normally stated in terms of their RMS values. Deviations of these waveforms from their fundamental and sinusoidal component are normally expressed in terms of the THD (Total Harmonic Distortion) Factors.



Rms output voltage Vorms

$$V_{orms} = \left[\frac{1}{T} \int_0^T (V_s/2)^2 \, dt \right]^{1/2}$$

$$= \left[\frac{1}{T} \frac{V_s^2}{4} T \right]^{1/2}$$

$$= \left[\frac{V_s^2}{4} \right]^{1/2}$$

$$\boxed{V_{orms} = V_s/2}$$

Video Content / Details of website for further learning (if any):

- https://nptel.ac.in/content/storage2/courses/108103009/download/M5.pdf

Important Books/Journals for further learning including the page nos.: 150-151

P.S.Bimbra “Power Electronics” Khanna Publishers, third Edition, 2003.

Course Faculty

L29

LECTURE HANDOUTS

EEE | **III / V**

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit IV : DC - AC Converters **Date of Lecture:**

Topic of Lecture:

Single phase voltage source inverter

Introduction :

- Inverter circuits supply AC voltage or current to a load from a DC supply. A DC source, often obtained from an AC-DC rectifier, is converted into an AC source of some frequency. A uninterruptible AC supply is an example where the 50 Hz AC power output from the inverter replaces the 50 Hz AC mains supply when the latter is lost due to a fault condition.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Rectification
- Basics of Voltage source inverter

Single phase voltage source inverter

✓ A voltage source inverter or VSI is a device that converts unidirectional voltage waveform into a bidirectional voltage waveform, in other words, it is a converter that converts its voltage from DC form to AC form. An ideal voltage source inverter keeps the voltage constant through-out the process.

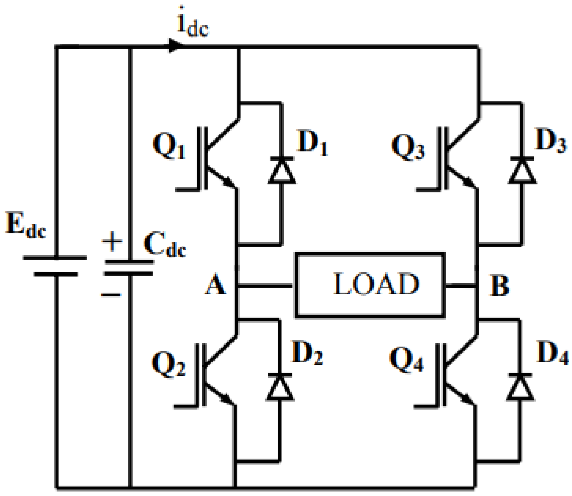
✓ A VSI usually consists of a DC voltage source, voltage source, a transistor for switching purposes, and one large DC link capacitor. A DC voltage source can be a battery or a dynamo, or a solar cell, a transistor used maybe an IGBT, BJT, MOSFET, GTO. VSI can be represented in 2 topologies, are single-phase and a 3-phase inverter, where each phase can be further classified into a Half-bridge inverter and full-bridge inverter.

✓ The full-bridge inverter is similar to the half bridge-inverter, but it has an additional leg to connect the neutral point to the load. Figure shows the circuit schematic of the single-phase voltage source full-bridge inverter.

✓ To avoid shorting out the voltage source, S1+ and S1- cannot be on at the same time, and S2+ and S2- also cannot be on at the same time. Any modulating technique used for the full-bridge configuration should have either the top or the bottom switch of each leg on at any given time. Due to the extra leg, the maximum amplitude of the output waveform is Vi, and is twice as large as the maximum achievable output amplitude for the half-bridge configuration.

- ✓ States 1 and 2 from Table 2 are used to generate the AC output voltage with bipolar SPWM. The AC output voltage can take on only two values, either Vi or –Vi. To generate these same states using a half-bridge configuration, a carrier based technique can be used.

- ✓ S+ being on for the half-bridge corresponds to S1+ and S2- being on for the full-bridge. Similarly, S- being on for the half-bridge corresponds to S1- and S2+ being on for the full bridge. The output voltage for this modulation technique is more or less sinusoidal, with a fundamental component that has an amplitude in the linear region of less than or equal to one **$v_{o1} = v_{ab1} = v_i \bullet m_a$.**



Video Content / Details of website for further learning (if any):

- https://subjects.ee.unsw.edu.au/elec4614/Lecture%2019%20-%20Single phase%20squarewave%20Inverters.pdf

Important Books/Journals for further learning including the page nos.: 152-154

P.S.Bimbra "Power Electronics" Khanna Publishers, third Edition, 2003.

Course Faculty

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit IV : DC - AC Converters **Date of Lecture:**

Topic of Lecture:

3 phase VSI 120 degree mode of inverter

Introduction :

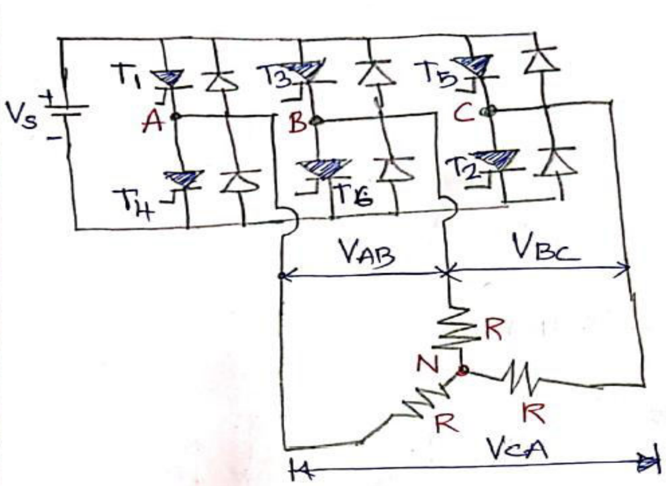
- Three-phase inverters are normally used for high-power applications. The gating signals of single-phase inverters should be advanced or delayed by with respect to each other in order to obtain three phase balanced (fundamental) voltages.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Rectifier
- Triggering

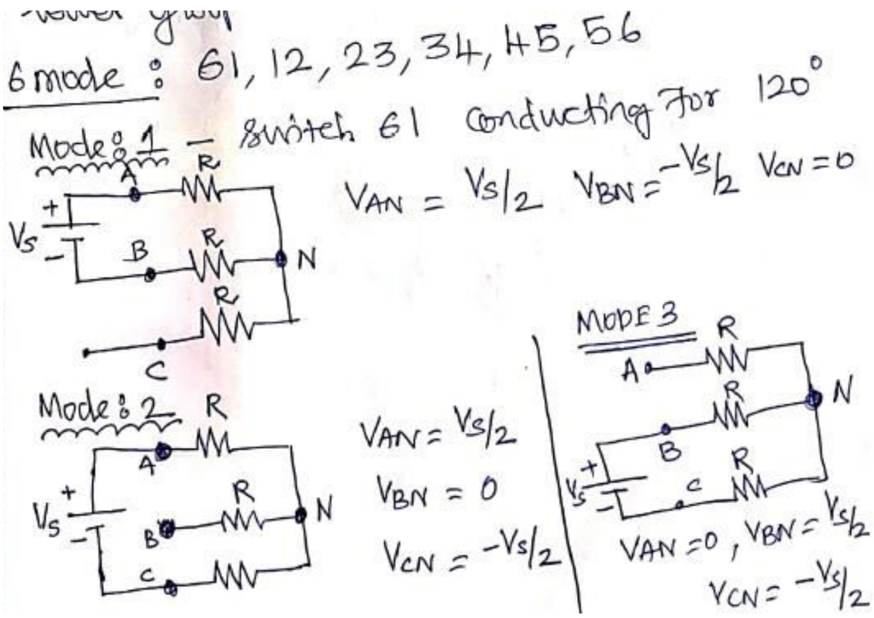
3 phase 120 degree mode of inverter

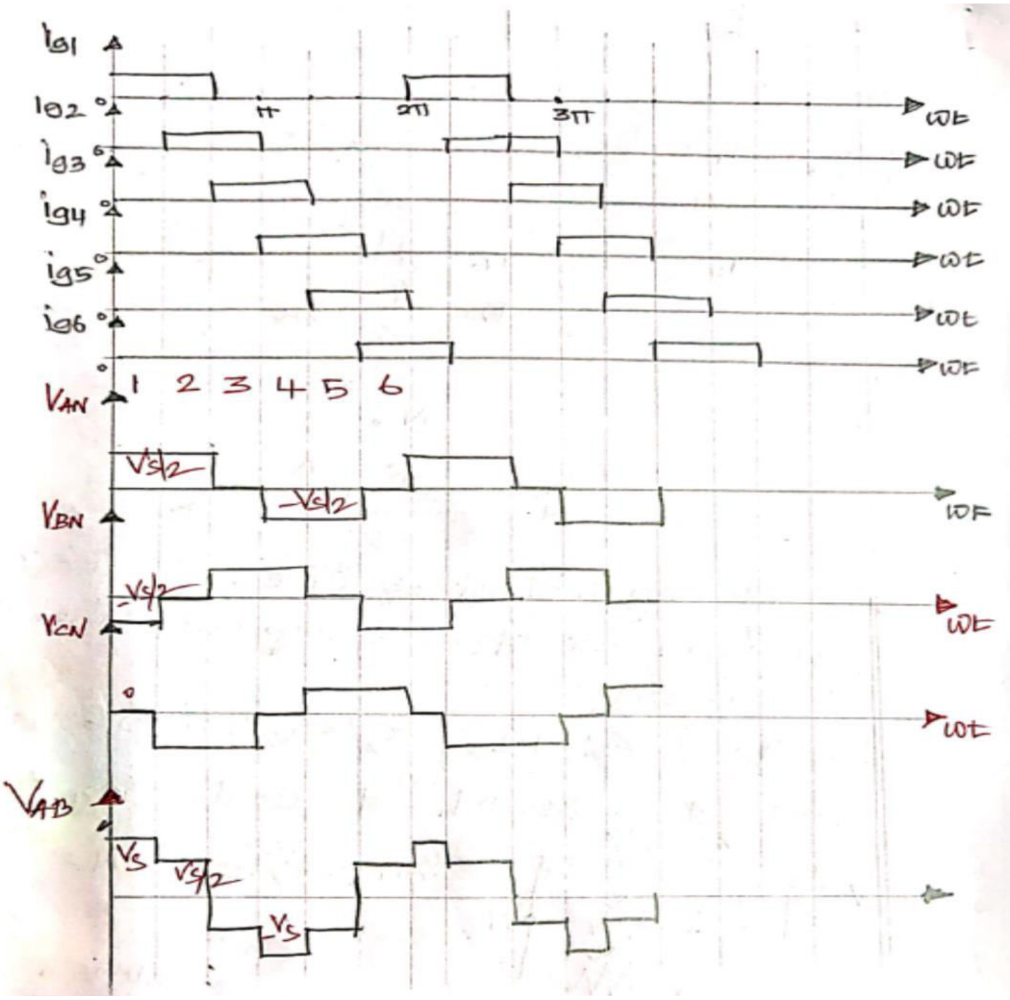
- ✓ When transistor T1 is switched on, terminal a is connected to the positive terminal of the dc input voltage. When transistor T4 is switched on, terminal a is brought to the negative terminal of the dc source.
- ✓ There are two types of conductions depending on the control signal used: 1. 120^0 conduction. 2.180^0 conduction. In this context we shall consider 120^0 conduction mode only for clarity. 120 – Degree conduction:



- ✓ In this type of control, each thyristor (or Transistor) conducts for 120^0. Only two thyristors remain “ON” at any instant of time. The per phase and line- to-line voltage waveforms are shown in Figures

- ✓ For star connected load, three modes for three-phase bridge inverter operation exist. In each case, the effective resistance across the source is 2R as shown in figure.





Video Content / Details of website for further learning (if any):

- https://www.philadelphia.edu.jo/academics/mlazim/uploads/PE%20Lecture%20No.15.pdf

Important Books/Journals for further learning including the page nos.: 155-160
P.S.Bimbra "Power Electronics" Khanna Publishers, third Edition, 2003.

Course Faculty

L31

LECTURE HANDOUTS

EEE **III / V**

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit IV : DC - AC Converters **Date of Lecture:**

Topic of Lecture:

3 phase 180 degree mode of inverter

Introduction :

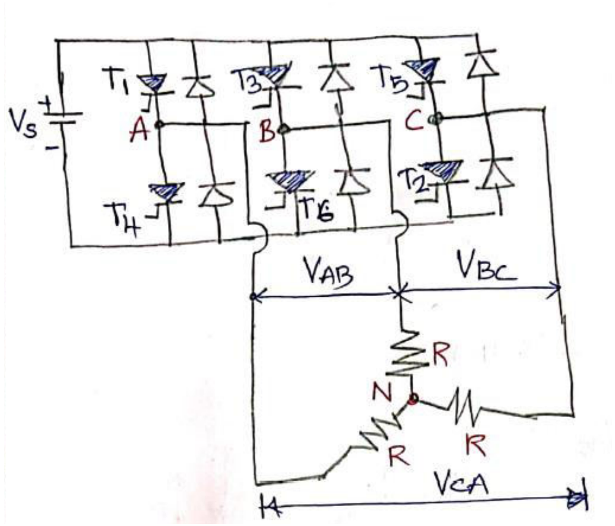
- Phase controlled rectification uses combinations of diodes and thyristors (SCR's) to convert the AC input voltage into a controlled DC output voltage. Fully-controlled rectifiers use four thyristors in their configuration, whereas half-controlled rectifiers use a combination of both thyristors and diodes.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Phase controlled rectification
- Operation of thyristors

3 phase 180 degree mode of inverter

✓ The configuration of the three phase inverter with star connected resistive load is shown in Figure. The following convention is followed: A current leaving a node point a, b or c and entering the neutral point n is assumed to be positive.



MODE	Thyristor conducting	Phase voltage			Line voltage		
		V_{AN}	V_{BN}	V_{CN}	V_{AB}	V_{BC}	V_{CA}
1	561	$V_s/3$	$-2V_s/3$	$V_s/3$	V_s	$-V_s$	0
2	612	$2V_s/3$	$-V_s/3$	$-V_s/3$	$+V_s$	0	$-V_s$
3	123	$V_s/3$	$V_s/3$	$-2V_s/3$	0	$+V_s$	$-V_s$
4	234	$-V_s/3$	$2V_s/3$	$-V_s/3$	$-V_s$	V_s	0
5	345	$-2V_s/3$	$V_s/3$	$V_s/3$	$-V_s$	0	V_s
6	456	$-V_s/3$	$-V_s/3$	$2V_s/3$	0	$-V_s$	V_s

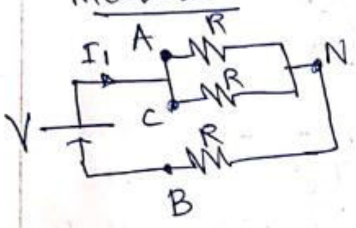
- ✓ All the three resistances are equal, In this mode of operation each switch conducts for 180 degree. Hence, at any instant of time three switches remain on. When T1 is on, the terminal a gets connected to the positive terminal of input DC source. Similarly, when T4 is on, terminal a gets connected to the negative terminal of input DC source. There are six possible modes of operation in a cycle and each mode is of 60 degree duration
- ✓ In 180 degree mode operation a maximum of three Thyristors conduct any instant and each SCR conduct for 180 radians in every cycle of the output. SCR pair in each leg T1T4, T3T6 a T5T2 are turned on with a time interval 180 degree and SCR T4 for nect 180 degree of a cycle.
- ✓ Upper group – T1T3T5 conduct at an interval of 120 degree, it means that, If SCR T1 is fired at zero degree then T3 must be triggered at 120 degree and T5 at 240 degree
- ✓ Lower group – T2T4T6 – conduct at an interval of 120 degree, it means that, If SCR T2 is fired at zero degree then T4 must be triggered at 120 degree and T6 at 240 degree

Phase voltage V_{AN}, V_{BN}, and V_{CN}

Line Voltage V_{AB}, V_{BC}, V_{CA}

$$V_{AB} = V_{AN} - V_{BN}$$

Mode 1



Total Resi

$$R_{equa} \,|\, R_T = R + R \| R = R + \frac{R}{2}$$

$$R_T = \frac{3R}{2}$$

Total current

$$I = V/R_T = \frac{V_s}{3R/2} = \frac{2V_s}{3R}$$

$$\therefore V_{AN} = V_{CN} = \frac{I_1 R}{2} = \frac{2V_s}{3R} \times \frac{R}{2}$$

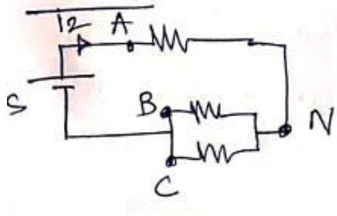
$$V_{AN} = V_{CN} = V_s/3$$

also

$$V_{BN} = -I_1 R = -\frac{2V_s}{3R} \times R$$

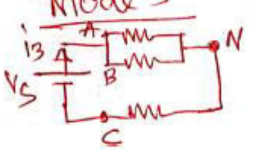
$$V_{BN} = -2V_s/3$$

Mode: 2



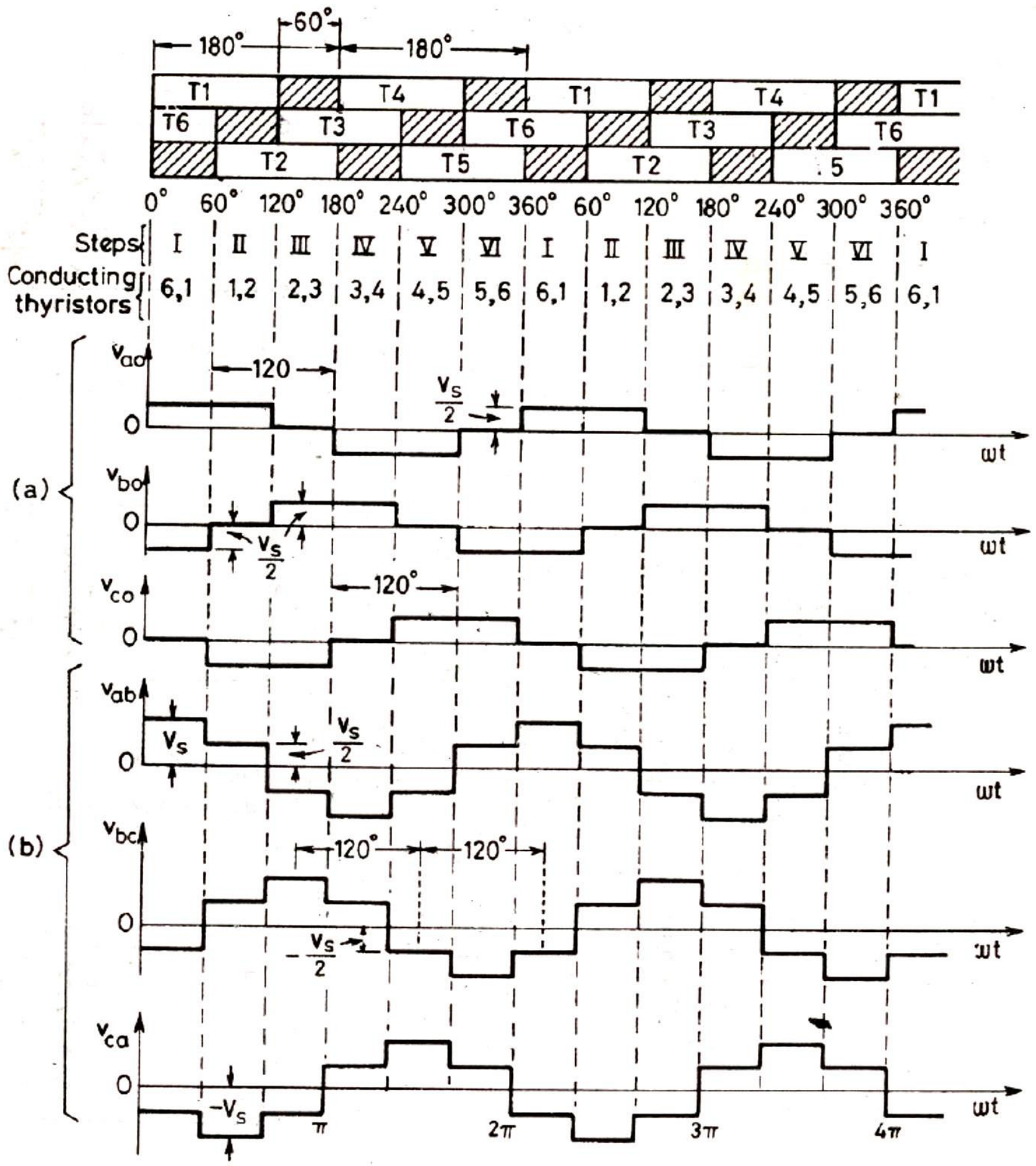
$$V_{AN} = 2V_s/3 \qquad V_{BN} = V_{CN} = \frac{-V_s}{3}$$

Mode 3



$$V_{AN} = V_{BN} = V_s/3$$

$$V_{CN} = \frac{-2V_s}{3}$$



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- https://nptel.ac.in/content/storage2/courses/108105066/PDF/L-10(DK)(PE)%20((EE)NPTEL).pdf

Important Books/Journals for further learning including the page nos.: 160-166

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Course Faculty

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(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
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Estd. 2000

L32

LECTURE HANDOUTS

EEE **III / V**

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit IV : DC - AC Converters **Date of Lecture:**

Topic of Lecture:

Voltage control of inverter using PWM

Introduction :

- The electric motors used in Electrical vehicle applications are required to have large speed ranges. Large speed ranges can be achieved by feeding the motor with voltages of different frequencies and also different voltage magnitudes. One of the most convenient voltage control technique to generate variable frequency and magnitude voltages is Pulse Width Modulation.

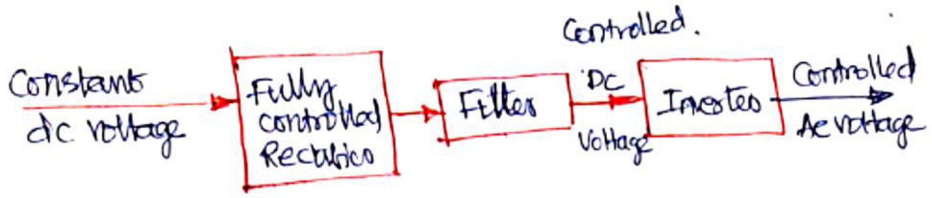
Prerequisite knowledge for Complete understanding and learning of Topic:

- Rectifier
- Switching devices

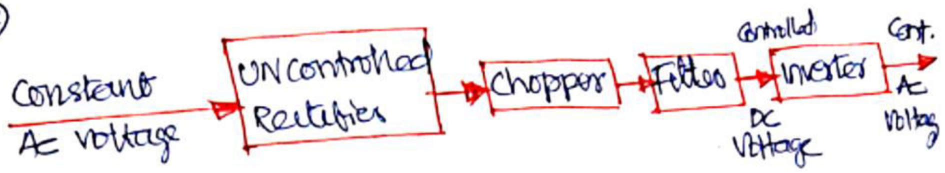
Voltage control of inverter using PWM

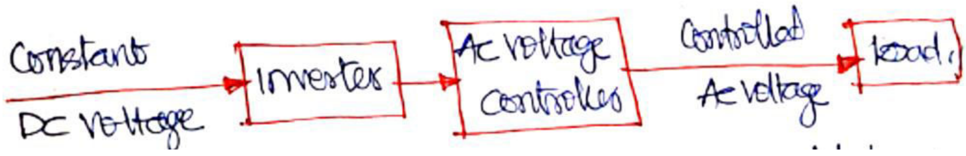
- ✓ The output voltage of inverter may not remain a constant value and voltage drop in inverter, at the same time some special application require variation in the input voltage and frequency. This is achieved by the following methods
- ✓ External control of ac output voltage, External control of DC input voltage and inverter control of inverter, the first two methods require additional components / circuits, where as third does not require additional components
- ✓ External control of DC input voltage and inverter – when the available voltage source is AC then Dc voltage input to the inverter is controlled through 1. Full controlled rectifier 2. Uncontrolled rectifier and chopper

1)



2)





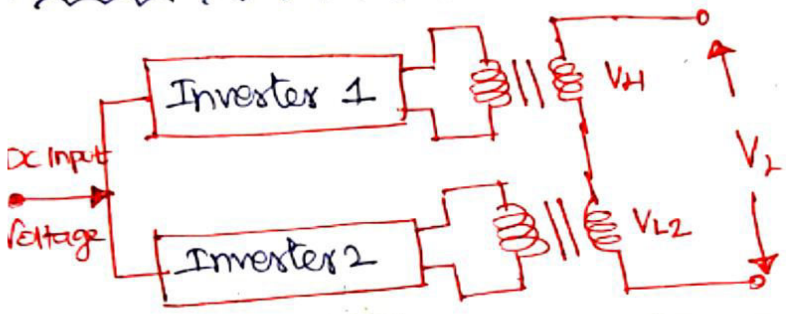
- ✓ An AC voltage controller is inserted between the output terminals of inverter and the load, through the firing angle control of AC voltage controller, the voltage input to the AC load is regulated, this method requires additional circuit and gating circuit and injecting higher order harmonics
- ✓ Internal control of inverter

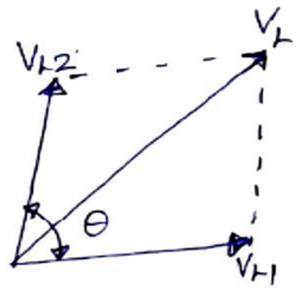
Inverter output voltage controlled within inverter itself.

a) Series inverter control

b) Pulse width modulation control

1) Series inverter control





the output voltage of two inverters can be summed up with the help of transformer to obtain an adjustable output voltage.

$$V_L = \left[V_{L1}^2 + V_{L2}^2 + 2 V_{L1} V_{L2} \cos\theta\right]^{1/2}$$

when θ is zero

$$V_L = V_{L1} + V_{L2}$$

Angle θ can be varied by the firing angle control of two inverters.

2) Pulse width modulation control

Fixed dc input voltage converted into controlled AC output voltage

This can be achieved by adjusting the on and off periods of the inverter (power semiconductor) switches.

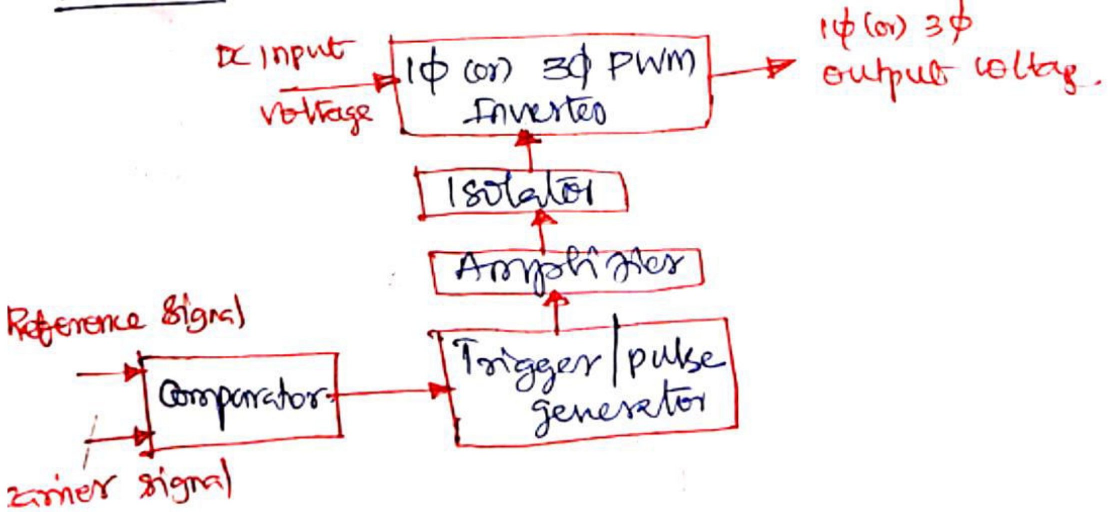
1) The output voltage control can be obtained without any additional components

2) The lower order harmonics can be eliminated or minimised along with its output voltage control.

Types of PWM

1) Multiple pulse width Modulation
2) Sinusoidal pulse width modulation
3) modified Sinusoidal PWM.

PWM



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Course Faculty

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LECTURE HANDOUTS

L34

EEE

III / V

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit IV : **DC - AC Converters** **Date of Lecture:**

Topic of Lecture:

Single PWM and Multiple PWM

Introduction :

- Pulse Width Modulation method is a fixed dc input voltage is given to the inverters and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. This is the most popular method of controlling the output voltage and in this method is known as pulse width modulation

Prerequisite knowledge for Complete understanding and learning of Topic:

- Reference and carrier signal
- Pulse width modulation

Single PWM

- ✓ As the semiconductor device receives only one pulse during one half cycle, one semiconductor device is switched on. The output voltage of the inverter can be controlled by controlling width of pulse.
- ✓ Figure shows the gate signal and output voltage waveform for single phase full bridge inverter.
- ✓ The gate signal is generated by comparing VR amplitude reference signal and VC amplitude control signal. The width of gate pulse can be varies from 0o to 180o by controlling the reference signal from 0 to VR. This will control the output voltage of the inverter.
- ✓ The frequency of the output voltage depends upon frequency of reference signal.The amplitude modulation M is ratio of reference signal (VR) and carrier signal (VC).

  $M = V_R / V_C$

Multiple PWM

- ✓ Types of PWM technique Different types of PWM control technique is given as follows Single pulse width modulation (Single PWM) Multiple pulse width modulation (MPWM) Sinusoidal pulse width modulation (SPWM) Modified Sinusoidal pulse width modulation (MSPWM)

- ✓ In single pulse width modulation control technique only one pulse will be there for every half cycle. The width of the single pulse can be adjusted in order to control the output voltage of the inverter. By comparing rectangular reference signal of amplitude (Ar) and a triangular carrier wave (Ac), the gating signals can be generated

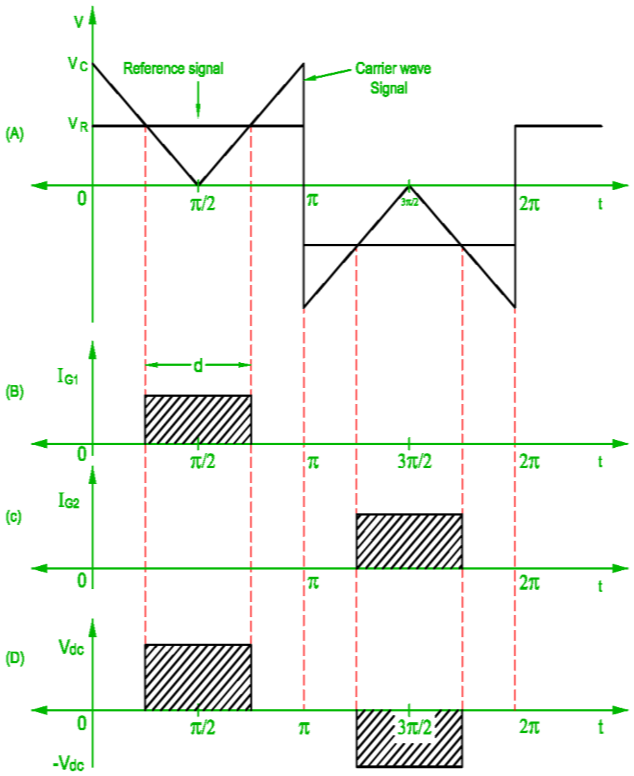
- ✓ The main drawback of single PWM technique is high harmonic content. In order to reduce the harmonic content, the multiple PWM technique is used, in which several pulses are given in each half cycle of output voltage. The generation of gating signal is achieved by comparing the reference signal of the amplitude (Ar) with a triangular carrier wave (Ac)

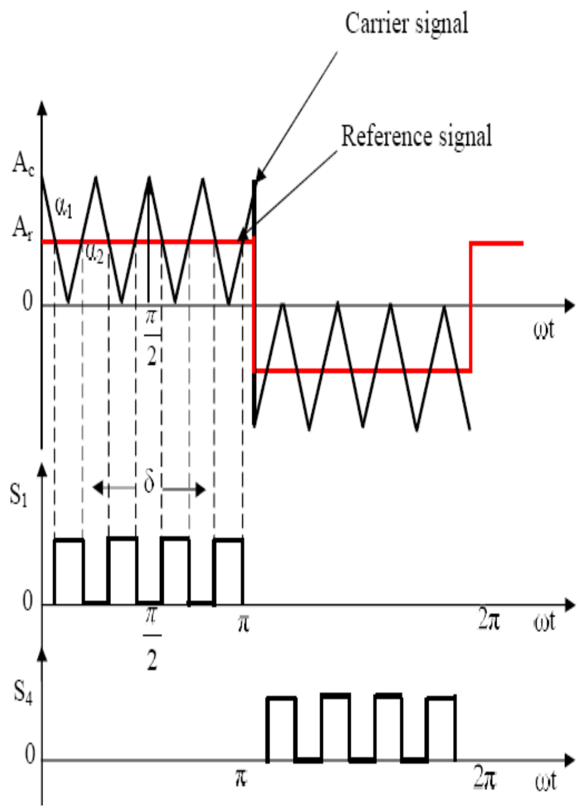
- ✓ The output frequency (fo) is determined by the frequency of the reference signal. The output voltage can be controlled by modulation index. The number of pulses (p) per half cycle is calculated by the carrier frequency (fc). Number of pulses per half cycle is found by

$$p = \frac{f_c}{2f_o}, \qquad = \frac{m_f}{2}, \quad \text{where} \quad m_f = \frac{f_c}{f_o}$$

- ✓ The instantaneous output voltage of the inverter can be given as

$$V_O = V_s(S_1 - S_4)$$





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- https://shodhganga.inflibnet.ac.in/bitstream/10603/33606/10/10_chapter5.pdf

Important Books/Journals for further learning including the page nos.: 173-174
P.S.Bimbra “Power Electronics” Khanna Publishers, third Edition, 2003.

Course Faculty

L34

LECTURE HANDOUTS

EEE

III / V

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit IV : **DC - AC Converters** **Date of Lecture:**

Topic of Lecture:

Sinusoidal PWM and Modified SPWM

Introduction :

- Pulse Width Modulation method is a fixed dc input voltage is given to the inverters and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. This is the most popular method of controlling the output voltage and in this method is known as pulse width modulation

Prerequisite knowledge for Complete understanding and learning of Topic:

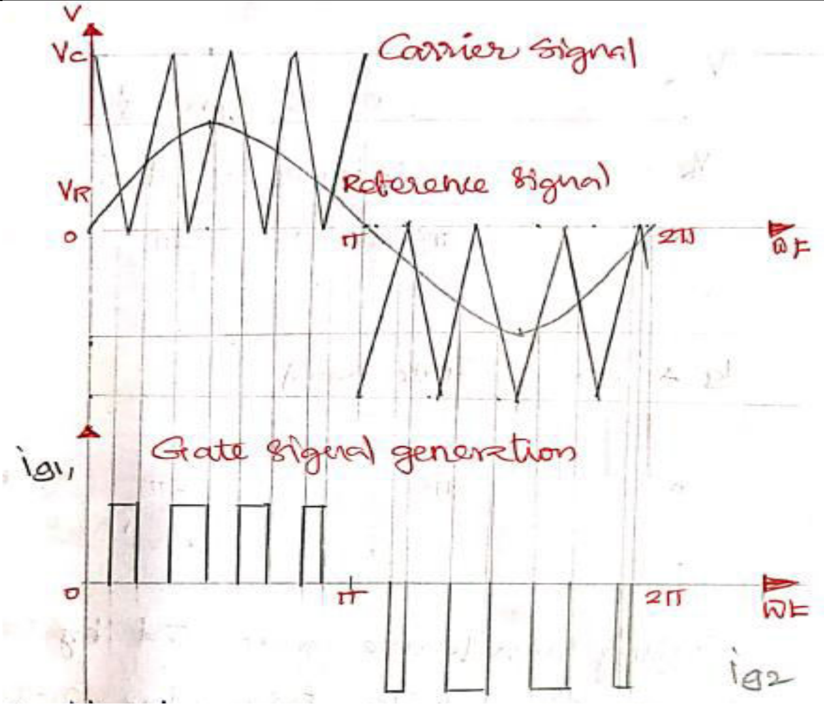
- Operation of converter
- Pulse width modulation

Sinusoidal PWM

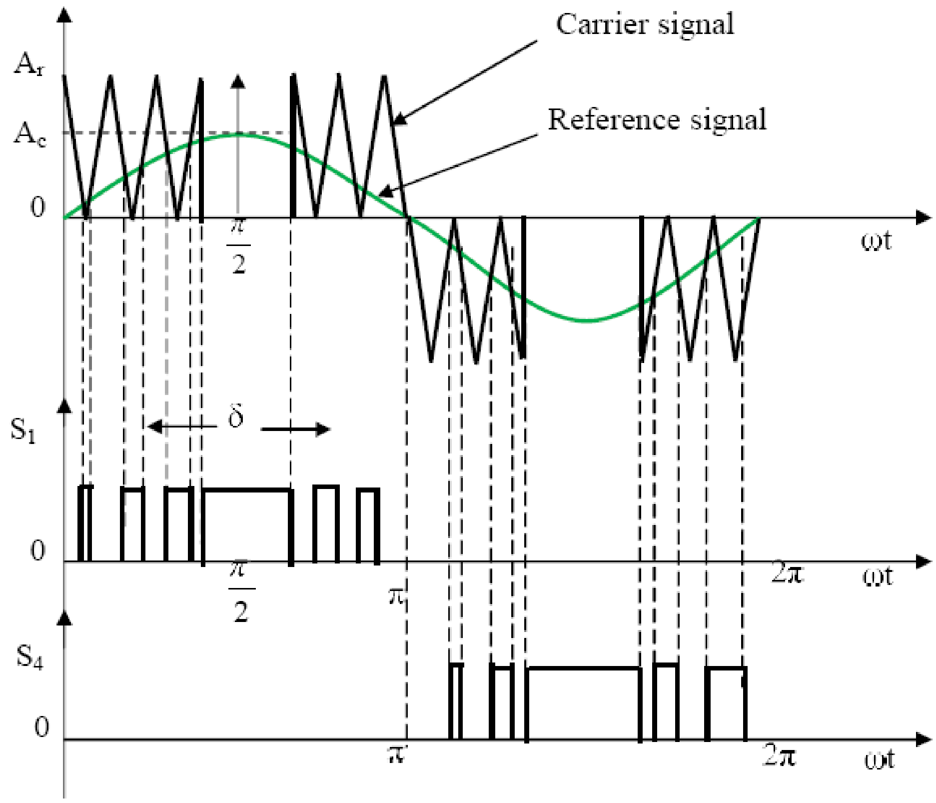
- ✓ The generation of a sinusoidal PWM signal, which finds more applications in industries. the gating signal can be generated by comparing a sinusoidal reference signal with a triangular carrier wave and the width of each pulse varied proportionally to the amplitude of a sine wave evaluated at the center of the same pulse.
- ✓ The output frequency (fo) of the inverter can be found by using the frequency of the reference signal (fr). The rms output voltage (vo) can be controlled by modulation index M and in turn modulation index is controlled by peak amplitude (Ar). The voltage can be calculated byVO Vs S1 S4 . The number of pulses per half cycle depends on the carrier frequency.
- ✓ The gating signal can be produced by using the unidirectional triangular carrier wave.

Modified SPWM

- ✓ When considering sinusoidal PWM waveform, the pulse width does not change significantly with the variation of modulation index. The reason is due to the characteristics of the sine wave. Hence this sinusoidal PWM technique is modified so that the carrier signal is applied during the first and last 60 degree intervals per half cycle as shown in Figure.
- ✓ The fundamental component is increased and its harmonic characteristics are improved. The main advantages of this technique is increased fundamental component, improved harmonic characteristics, reduced number of switching power devices and decreased switching losses.



Modified SPWM



- ✓ **Advantages of PWM -** The output voltage control with method can be obtained without any additional components, With this method, lower order harmonic can be eliminated or minimized along with it's output voltage control. It reduces the filtering requirements

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Course Faculty

L35

LECTURE HANDOUTS

EEE **III / V**

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit IV : **DC - AC Converters** **Date of Lecture:**

Topic of Lecture:

Harmonic reduction techniques

Introduction :

- PWM method is frequently used in vector controlled and direct torque controlled drives. In vector controlled drive this technique is used for reference voltage generation when current control is exercised in rotating reference frame.

Prerequisite knowledge for Complete understanding and learning of Topic:

- PQ theory
- Basic of real and reactive power

Harmonic reduction techniques

Sources of Triple harmonics

- ✓ The triple harmonics are generated by single phase non linear load that have common neutral.
- ✓ These non linear loads are common in office, hospitals, commercial buildings, educational building, IT offices. Some of examples are
  (1) Compact Fluorescent Lamp
  (2) Electronic ballast
  (3) SMPS in the Computer

Triple Harmonic in Neutral Conductor

- ✓ If the load is balanced, the neutral current is zero as the vector sum of all three phase current is zero.
- ✓ The current flows through neutral conductor in spite of load are balanced due to presence of triple harmonics.
- ✓ All the triple harmonics are zero sequence in nature and they are in phase with all the three phases R, Y and B.
- ✓ The neutral current increases up to 2 times phase current due to presence of third harmonics.

Causes of Triple harmonic

- ✓ Burning of neutral conductor due to overloading on it (or size of the neutral conductor must be kept higher in order to consider effect of third harmonic)
- ✓ Cable overheating due to skin effect
- ✓ Over heating of distribution transformer
- ✓ Higher eddy current losses as the eddy current losses is directly proportional to square of the frequency
- ✓ Due to heating, it will reduce the life of transformer, switch gear and other switching devices

Methods to Reduce / Mitigation Triple harmonic

- ✓ The Detuned filter (Type of passive filter consists of series combination of power capacitor and reactor which offer higher impedance for higher frequency harmonics) is used to reduce the effect of triple harmonic.
- ✓ The tuning frequency of the detuned filter is 133 Hz, which is below third harmonic frequency (150 Hz).
- ✓ The amplification of 3^{rd} harmonic is reduced by this filter. However this filter does not eliminate the harmonic completely.
- ✓ Tuned single arm passive filter.
- ✓ Tuned multiple arm passive filter.
- ✓ External active filter.

Video Content / Details of website for further learning (if any):

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Important Books/Journals for further learning including the page nos.: 175 - 178

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Course Faculty

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit IV : DC - AC Converters **Date of Lecture:**

Topic of Lecture:

Single phase Current Source Inverter

Introduction :

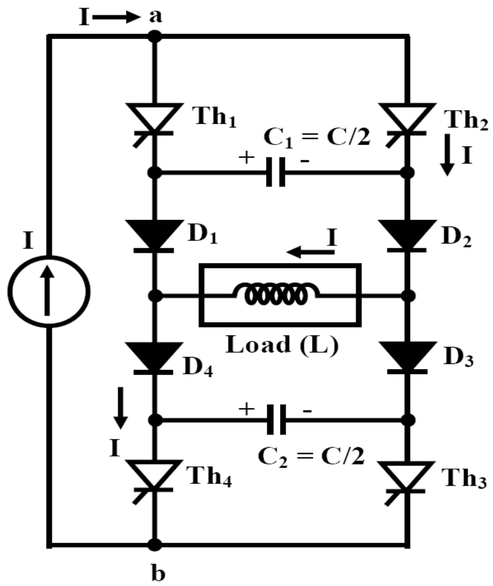
- For the VSI, as the full form denotes, the output voltage is constant, with the output current changing with the load type, and/or the values of the components. But in the CSI, the current is nearly constant. The voltage changes here, as the load is changed. In an Induction motor, the developed torque changes with the change in the load torque, the speed being constant, with no acceleration/deceleration.

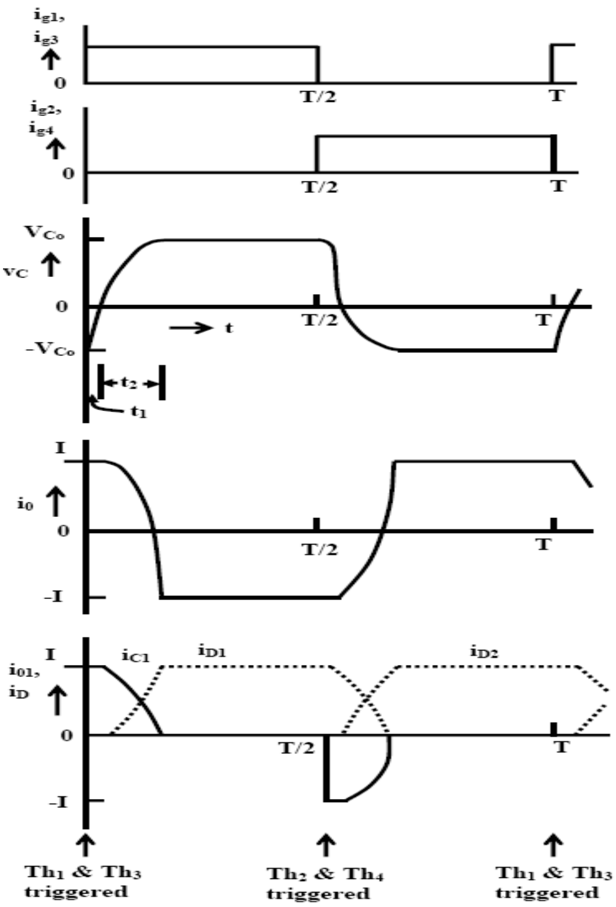
Prerequisite knowledge for Complete understanding and learning of Topic:

- Voltage source inverter
- Converter and inverter operation

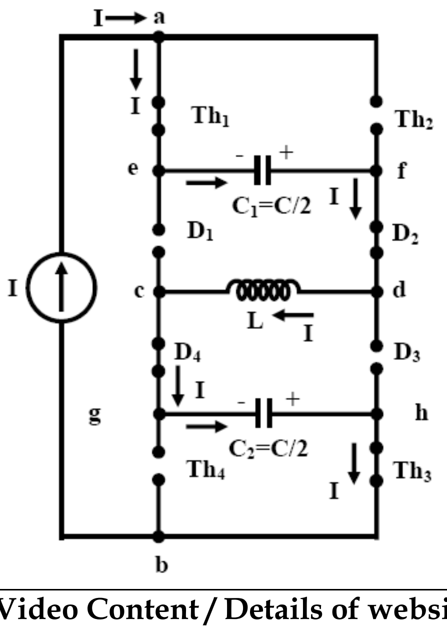
Current source inverter

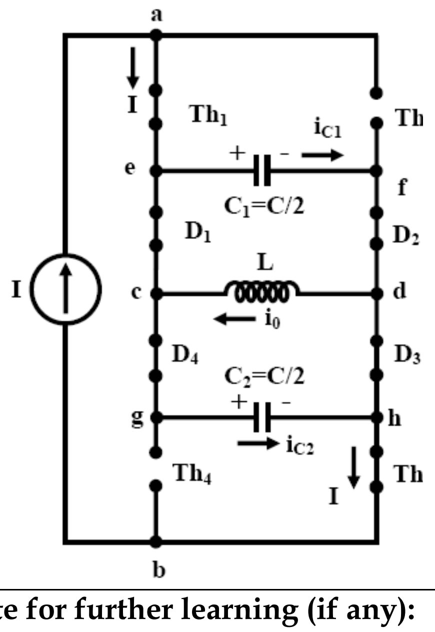
- ✓ Assuming that the converter operates in conduction mode and the ripple from the load current is negligible, the open circuit voltage becomes equal to average DC output at a firing angle of α.The diagram below shows a fully controlled converter with source in single phase. The thyristors T3 and T4 are assumed to be in conduction mode when t = 0. On the other hand, T1 and T2 fire when ωt = α
- ✓ The circuit of a Single-phase Current Source Inverter (CSI) is shown in Figure. The type of operation is termed as Auto-Sequential Commutated Inverter (ASCI). A constant current source is assumed here, which may be realized by using an inductance of suitable value, which must be high, in series with the current limited dc voltage source. The thyristor pairs, Th1 & Th3, and Th2 & Th4, are alternatively turned ON to obtain a nearly square wave current waveform.
- ✓ Two commutating capacitors − C1 in the upper half, and C2 in the lower half, are used. Four diodes, D1–D4 are connected in series with each thyristor to prevent the commutating capacitors from discharging into the load. The output frequency of the inverter is controlled in the usual way, i.e., by varying the half time period, (T/2), at which the thyristors in pair are triggered by pulses being fed to the respective gates by the control circuit, to turn them ON, as can be observed from the waveforms figure. The inductance (L) is taken as the load in this case, the reason(s) for which need not be stated, being well known. The operation is explained by two modes.
- ✓ The circuit for this mode is shown in Figure. The following are the assumptions. Starting from the instant, , the thyristor pair, Th−=0t_2 & Th_4, is conducting (ON), and the current (I) flows through the path, Th_2, D_2, load (L), D_4, Th_4, and source, I.

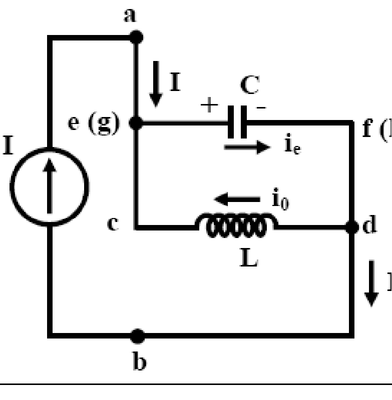




- ✓ The commutating capacitors are initially charged equally with the polarity as given, i.e., . This means that both capacitors have right hand plate positive and left hand plate negative. If two capacitors are not charged initially, they have to pre-charged.







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Course Faculty

L37

LECTURE HANDOUTS

EEE **III / V**

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit V : AC to AC Converters **Date of Lecture:**

Topic of Lecture:

Introduction to AC voltage controller

Introduction :

- A single-phase AC controller voltage controller voltage controller is used to vary the value of the alternating voltage after it has been applied to a load circuit. A thyristor is also placed between the load and the constant source of AC voltage.
- The root mean square alternating voltage is regulated by changing the thyristor triggering angle. In the case of phase control, the thyristors are employed as switches to establish a connection from the AC input supply to the load circuit during each input cycle. For every positive input voltage, chopping occurs and voltage is reduced.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Thyristor
- Regulator

Introduction to AC voltage controller

- ✓ AC Voltage Controller is a thyristor based device which converts fixed alternating voltage directly to variable alternating voltage without a change in frequency.
- ✓ AC Voltage Controller is a phase-controlled device and hence no force commutation circuitry is required. Natural or line commutation is used. Phase control means that the phase relationship between the start of load current and supply voltage is controlled by varying the firing angle of thyristor used in the circuit of ac voltage controller.
- ✓ The working principle of AC Voltage Controller is based on either of two methods: ***Phase Control or Integral Cycle Control.***
- ✓ In Phase Control method, the phase relationship between the start of load current and the input supply voltage is controlled by controlling the firing angle of the thyristor.
- ✓ In Integral Cycle Control, the AC input supply is switched ON for some integral cycles and

turned OFF for further number of integral cycles.

- ✓ Integral cycle control is mainly used for applications where the mechanical time constant or thermal time constant is quite high of the order of some seconds.
- ✓ For example, mechanical time constant for many of the speed control drives, or the thermal time constant of the heating loads is usually quite high.
- ✓ For such applications, almost no variation in speed or temperature will be noticed if the control is achieved by connection the load to the source for some on-cycles and then disconnecting the load for some off-cycles. This form of power control is the integral cycle control.

Application of AC Voltage Controller:

Some of the main application of AC Voltage Controller are for the following:

- ✓ Domestic and industrial heating
- ✓ Transformer tap changing
- ✓ Lighting control
- ✓ Speed Control of single phase and three phase AC drives
- ✓ Starting of Induction Motors
- ✓ Earlier the devices were used for the above applications were auto-transformer, tap-changing transformers, magnetic amplifiers, saturable reactors etc. But these devices are now replaced by thyristor and TRIAC based AC Voltage Controller because of their high efficiency, flexibility in control, compact size and less maintenance requirement. AC voltage controllers are also adaptable for closed-loop control system.
- ✓ The main disadvantage of AC voltage controller is the introduction of objectionable harmonics in the supply current and load voltage waveform, particularly at reduced output voltage level.

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Course Faculty

LECTURE HANDOUTS

L38

EEE

III / V

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit V : AC to AC Converters **Date of Lecture:**

Topic of Lecture:

Single phase AC voltage controller with R load

Introduction :

- A single-phase AC controller voltage controller voltage controller is used to vary the value of the alternating voltage after it has been applied to a load circuit. A thyristor is also placed between the load and the constant source of AC voltage.
- The root mean square alternating voltage is regulated by changing the thyristor triggering angle. In the case of phase control, the thyristors are employed as switches to establish a connection from the AC input supply to the load circuit during each input cycle. For every positive input voltage, chopping occurs and voltage is reduced.

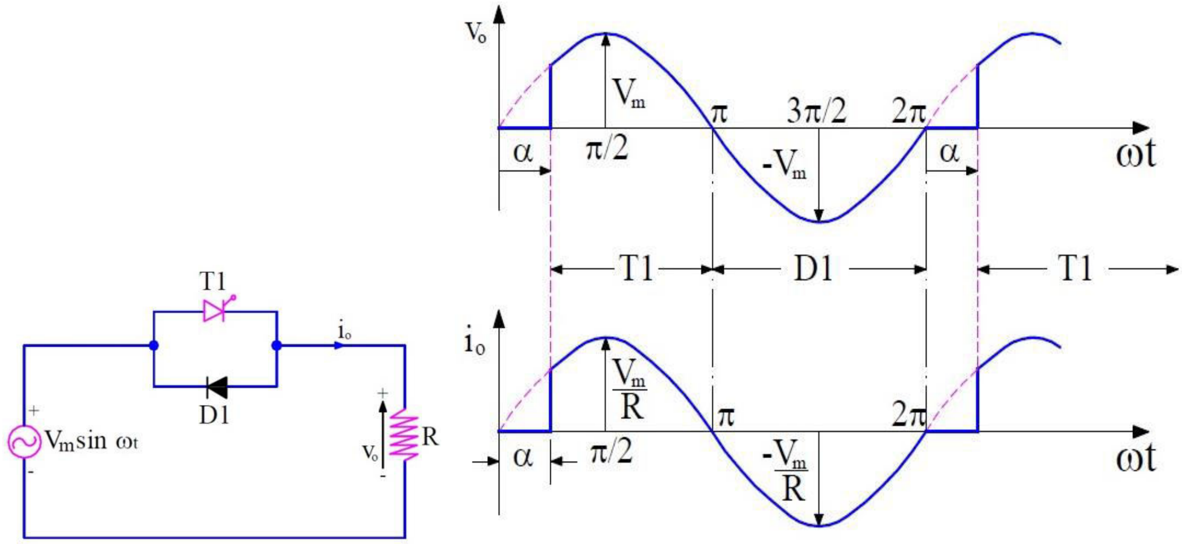
Prerequisite knowledge for Complete understanding and learning of Topic:

- Thyristor
- Regulator

Single phase AC voltage controller

- ✓ Single Phase AC Voltage Controller is a device which converts fixed single phase alternating voltage directly to a variable alternating voltage without a change in frequency. The input and output of the device is single phase.
- ✓ There are two types of single phase AC Voltage Controller: ***Single phase Half Wave and Single phase Full Wave***. In this article, we will discuss both type of voltage controller in detail and illustrate the working with relevant circuit diagram and waveforms.
- ✓ The working principle of any voltage controller is based on sequence of switching operation of some power switches viz. thyristors. The thyristors are so switched on that load gets connected to AC source for a part of each half cycle of input voltage. Thus, the output voltage follows the part of input AC voltage for which the load is connected to source. In this way, the output voltage is controlled.

- ✓ Let us consider single phase half wave & full wave AC voltage controller for understanding the working principle.
- ✓ A single phase half wave AC voltage controller comprises of a thyristor connected in anti-parallel with a power diode. The circuit diagram is shown in figure below.
- ✓ The load is assumed resistive for the sake of simplicity. The input source is $V_m Sin\omega t$.
- ✓ For the positive half cycle of input source, thyristor T1 is forward biased and hence it is able to conduct provided gate signal is applied. This means that T1 will remain OFF until gate signal is applied. Now suppose, at some angle α (called the firing angle), thyristor T1 is gated. As soon as T1 is fired / gated, it starts conducting and hence, load gets directly connected to the source. This makes load voltage $V_o = V_m Sin\alpha$ and load current $I_o = (V_m Sin\alpha / R)$ at the instant T1 is fired. From ωt = α to π, the load voltage and current follows the input voltage waveform $V_m Sin\omega t$ and $(V_m Sin\omega t / R)$ respectively.
- ✓ After ωt = π, thyristor T1 becomes reversed biased and the load current becomes zero (note that load voltage and current are in phase, hence as soon as load voltage becomes zero, load current also becomes zero) and hence thyristor T1 is commutated naturally.
- ✓ After ωt = π, diode D1 becomes forward biased and hence starts conducting. This makes load voltage & current to follow the supply voltage $V_m Sin\omega t$ and $(V_m Sin\omega t / R)$ respectively for the negative half cycle.
- ✓ The output waveform for load voltage & current is shown below.



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Course Faculty

LECTURE HANDOUTS

L39

EEE

III / V

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit V : AC to AC Converters **Date of Lecture:**

Topic of Lecture:

Single phase AC voltage controller with RL load

Introduction :

- A single-phase AC controller voltage controller voltage controller is used to vary the value of the alternating voltage after it has been applied to a load circuit. A thyristor is also placed between the load and the constant source of AC voltage.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Thyristor
- Regulator

Single phase AC voltage controller

✓ The single –phase AC controller with resistive load is shown in Fig.11.1.Due to the inductance in the circuit , the current in thyristor T1 would not fall to zero at ωt = π, when the source voltage vs start to be negative. Thyristor T1 continues to conduct until its current i1 falls to zero at ωt =β.

By KVL;

$v_s = v_o = V_R + v_L$

The equation for the current through R-L load can be found from the solution of the differential equation:

$$L\frac{di}{dt} + i\,R = V_m \sin \omega t$$

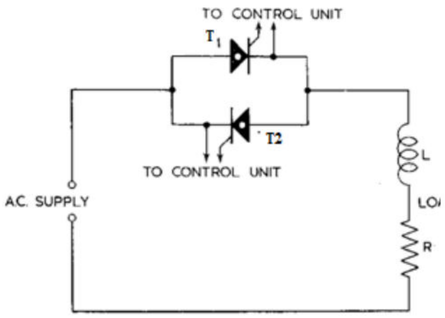
The solution of this differential equation is:

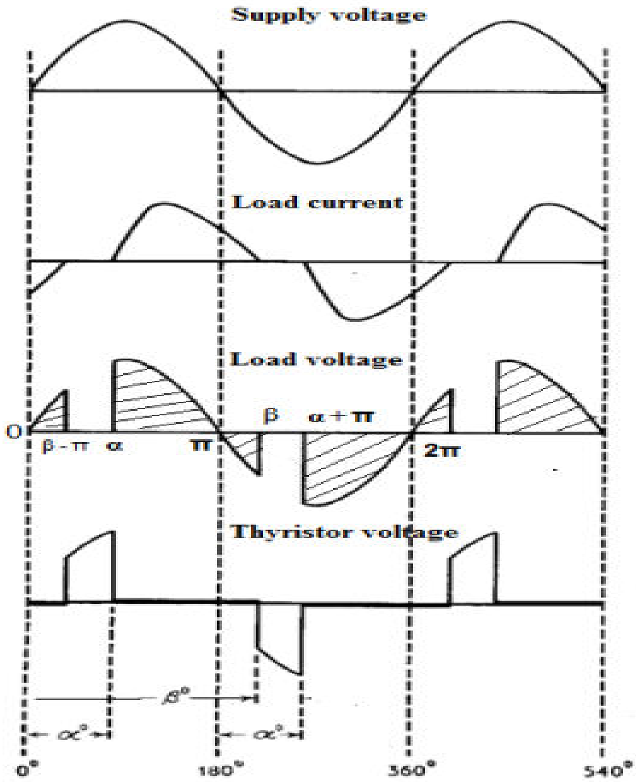
- The start of conduction is delayed until $\omega t = \alpha$. Subsequent to triggering, let the instantaneous current $i(\omega t)$ consists of hypothetical steady-state components $i_{ss}(\omega t)$ and transient component $i_{trans}(\omega t)$,

$$\therefore i(\omega t) = i_{ss}(\omega t) + i_{trans}(\omega t)$$

Now at $\omega t = \alpha$, the instantaneous steady-state component has the value,

✓





$$a_1 = \frac{V_m}{2\pi}[\int_0^{\beta-\pi} sin2\omega t \ \ d\omega t + \int_\alpha^{\beta} sin2\omega t \ \ d\omega t + \int_{\alpha+\pi}^{2\pi} sin\omega t \ \ d\omega t]$$

$$a_1 = \frac{V_m}{4\pi}\Big[-cos2\omega t \left\{ {\beta - \pi \atop 0} \right. - cos2\omega t \left\{ {\beta \atop \alpha} \right. - cos2\omega t \left\{ {2\pi \atop \pi + \alpha} \right. \ \ \Big]$$

$$a_1 = \frac{V_m}{2\pi}[\cos 2\alpha - \cos 2\beta]$$

$$b_1 = \frac{1}{\pi}\int_0^{2\pi} v_L(\omega t) \ sin\omega t \ d\omega t$$

$$b_1 = \frac{1}{\pi}\int_0^{\beta-\pi} V_m sin\omega t \ \ sin\omega t \ d\omega t + \frac{1}{\pi}\int_\alpha^{\beta} V_m sin\omega t \ \ sin\omega t \ d\omega t + \frac{1}{\pi}\int_{\alpha+\pi}^{2\pi} V_m sin\omega t \ \ sin \ \omega t \ d\omega t$$

$$b_1 = \frac{V_m}{2\pi}[2(\beta - \alpha) - \sin 2\beta + \sin 2\alpha]$$

Video Content / Details of website for further learning (if any):

- https://www.tutorialspoint.com.pdf

Important Books/Journals for further learning including the page nos.: 242-245

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L40

LECTURE HANDOUTS

EEE

III / V

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit V : AC to AC Converters **Date of Lecture:**

Topic of Lecture:

Control strategy and Power factor control

Introduction :

- Three-phase inverters are normally used for high-power applications. The gating signals of single-phase inverters should be advanced or delayed by with respect to each other in order to obtain three phase balanced (fundamental) voltages.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Switching Devices

Control strategy

- There are two different types of thyristor control used in practice to control the ac power flow •On-Off control •Phase control.These are the two ac output voltage control techniques.
- In On-Off control technique Thyristors are used as switches to connect the load circuit to the ac supply (source) for a few cycles of the input ac supply and then to disconnect it for few input cycles. The Thyristors thus act as a high speed contactor (or high speed ac switch).

Phase Control

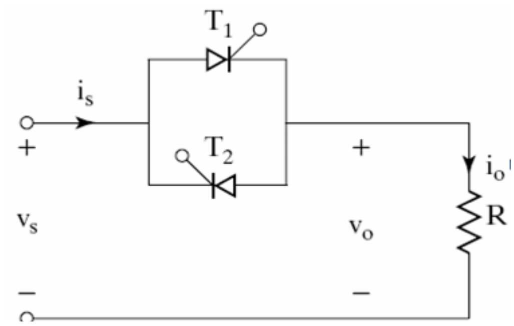
- In phase control the Thyristors are used as switches to connect the load circuit to the input ac supply, for a part of every input cycle. That is the ac supply voltage is chopped using Thyristors during a part of each input cycle.
- The thyristor switch is turned on for a part of every half cycle, so that input supply voltage appears across the load and then turned off during the remaining part of input half cycle to disconnect the ac supply from the load.
- By controlling the phase angle or the trigger angle α (delay angle), the output RMS voltage across the load can be controlled.
- Phase control Thyristors which are relatively inexpensive, converter grade Thyristors which are slower than fast switching inverter grade Thyristors are normally used. For applications upto 400Hz, if Triacs are available to meet the voltage and current ratings of a particular application,

Triacs are more commonly used.

- Due to ac line commutation or natural commutation, there is no need of extra commutation circuitry or components and the circuits for ac voltage controllers are very simple.

ON-OFF Control

The basic principle of on-off control technique is explained with reference to a single phase full wave ac voltage controller circuit shown below. The thyristor switches T_1 and T_2 are turned on by applying appropriate gate trigger pulses to connect the input ac supply to the load for 'n' number of input cycles during the time interval t_{ON}. The thyristor switches T_1 and T_2 are turned off by blocking the gate trigger pulses for 'm' number of input cycles during the time interval t_{OFF}. The ac controller ON time t_{ON} usually consists of an integral number of input cycles.



Power factor control

- Power factor control, also known as correction of power factor, is the process of reducing the amount of reactive power. The power electronic device used in this case is called a power factor controller (PFC).
- From the power triangle (which comprises reactive, true and apparent power), the reactive power is at right angle (90°) to the true power and is used to energize the magnetic field. Although reactive power does not have a real value in electronic equipment, the bill for electricity comprises real and reactive power costs.
- This makes it necessary to have power factor controllers in electronic devices. Power factor (k) is defined as the ratio of the real power (in kW) to the reactive power (in kVAr). Its value ranges from 0 to 1. If a device has a power factor of 0.8 and above, it is said to be using power efficiently.
- Incorporating a PFC ensures the power factor ranges from 0.95 to 0.99. Power factor controllers are mainly in industrial equipment to minimize reactive power generated by fluorescent lighting and electric motors.
- To ensure power factor is improved without causing harmonic distortion, the conventional capacitors should not be used. Instead, filters (combination of capacitors and reactors) for harmonic suppression are used. The figure below shows a harmonic filter.

Video Content / Details of website for further learning (if any):

- https://www.philadelphia.edu.jo/academics/mlazim/uploads/PE%20Lecture%20No.15.pdf

Important Books/Journals for further learning including the page nos.: 249-251

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LECTURE HANDOUTS

L41

EEE

III / V

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit V : AC to AC Converters **Date of Lecture:**

Topic of Lecture:

Control strategy - Multistage sequence control

Introduction :

- When two or more sequence control stages are connected, it is possible to have an improvement in power factor and further reduction in THD (total harmonic distortion). An n-stage sequence control converter has n windings in the transformer secondary part with each rated es/n (the source voltage).

Prerequisite knowledge for Complete understanding and learning of Topic:

- Converter
- Semiconductor Devices

Multistage sequence control

- When two AC converters are placed parallel to each other, the zero sequence way is created. A little difference between the two converters causes a great zero sequence in circulating current.
- The direction of the current is anti-clockwise with respect to that of the voltage system.
- A cycloconverter refers to a frequency changer that can to change AC power from one frequency to AC power at another frequency. This process is known as AC-AC conversion. It is mainly used in electric traction, AC motors having variable speed and induction heating.
- A cycloconverter can achieve frequency conversion in one stage and ensures that voltage and the frequencies are controllable. In addition, the need to use commutation circuits is not necessary because it utilizes natural commutation. Power transfer within a cycloconverter occurs in two directions (bidirectional).
- A major problem with cycloconverters is that when it is operating at small currents, there are inefficiencies created with firing delay. Furthermore, operations are only smooth at frequencies that are not equal half frequency input values.
- This is true because a cycloconverter is an AC- AC converter that is phase controlled. Therefore, for it to give the required AC output voltage, it has to do a selection of the voltage

input segments by applying line (natural) commutation. This explains why the output frequency is lower than the frequency input.

- Harmonics in a cycloconverter are mainly affected by methods of control, overlap effect, the number of pulses in a given cycle, operation mode and mode of conduction.

There are two types of cycloconverters

- **Step Up cycloconverter** − These types use natural commutation and give an output at higher frequency than that of the input.
- **Step Down cycloconverter** − This type uses forced commutation and results in an output with a frequency lower than that of the input.

Cycloconverters are further classified into three categories

- **Single phase to single-phase** − This type of cycloconverter has two full wave converters connected back to back. If one converter is operating the other one is disabled, no current passes through it.
- **Three-phase to single-phase** − This cycloconverter operates in four quadrants that is (+V, +I) and (−V, −I) being the rectification modes and (+V, −I) and (−V, +I) being the inversion modes.
- **Three-phase to three-phase** − This type of cycloconverter is majorly used in AC machine systems that are operating on three phase induction and synchronous machines.

Video Content / Details of website for further learning (if any):

- https://nptel.ac.in/content/storage2/courses/108103009/download/multisatage control.pdf

Important Books/Journals for further learning including the page nos.: 255-257

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L42

LECTURE HANDOUTS

EEE

III / V

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit V : AC to AC Converters **Date of Lecture:**

Topic of Lecture:

Cycloconverter - Step up and step down

Introduction :

- The circuit of a three-phase, three-wire ac regulator (termed as ac to ac voltage converter) with balanced resistive (star-connected) load, it may be noted that the resistance connected in all three phases are equal.
- Two thyristors connected back to back are used per phase, thus needing a total of six thyristors. Please note the numbering scheme, which is same as that used in a three-phase full-wave bridge converter or inverter

Prerequisite knowledge for Complete understanding and learning of Topic:

- Basics of Voltage source inverter

Step up Cycloconverter

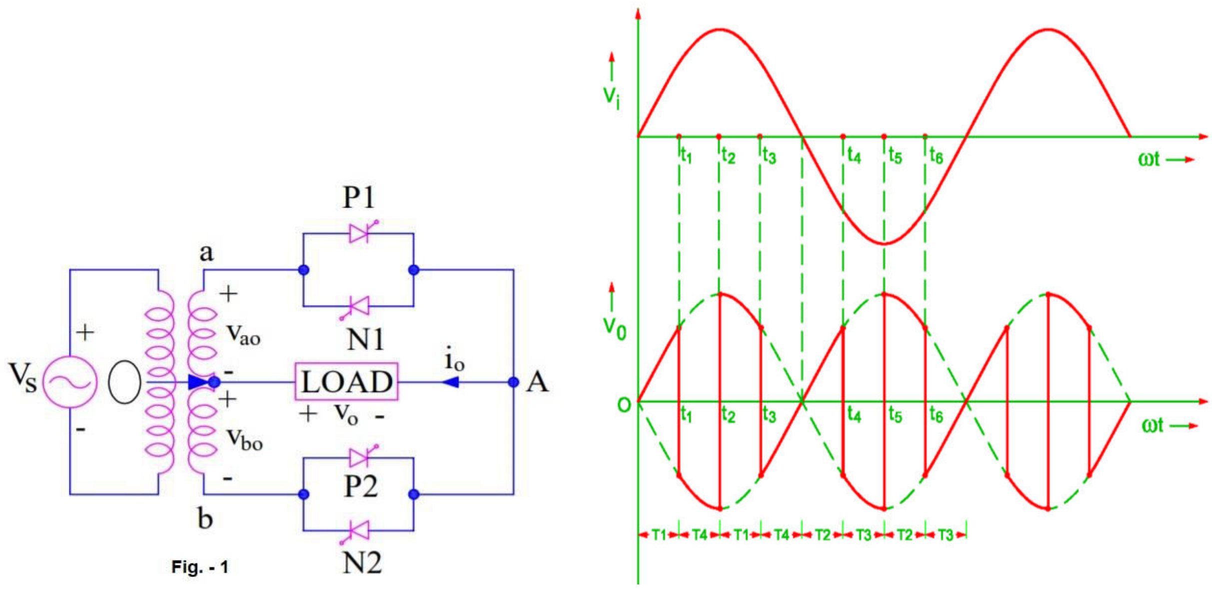

Fig. - 1

- It is only cyclo converter in which commutation of SCRs is done by forced commutation.
- The power circuit of the step up cyclo converter is shown in the figure A. There are two group of SCRs in which one group (SCR T1 and SCR T2) generates positive half cycle and other group (SCR T3 and SCR T4) generates negative half cycle.

- The output frequency of the cyclo converter is greater than the input frequency therefore it is called as step up cycloconverter.

Operation

The operation of the cyclo converter is explained as below.

Positive half cycle

- The SCR T1 is turned on during positive half cycle of the alternating supply during time 0 to t_1 therefore the load current flows through path A – SCR T1 – D – LOAD – C.
- The output voltage becomes positive. The SCR T1 is turned off by forced commutation at time t_1 and SCR T4 is turned on.
- The load current flows through path C – LOAD – D – SCR T4 – B.
- The output voltage becomes negative during this time.

Negative half cycle

- The SCR T2 is turned on during negative half cycle (at π time) of alternating cycle therefore the load current flows through path B – SCR T2 – D – LOAD – C .
- The output voltage becomes positive. The SCR T4 is tuned off at time t_4 by forced commutation and SCR T2 is turned on.
- The output voltage becomes negative during this time interval.
- The SCR T3 is turned off at time t_5 by forced commutation and SCR T2 is again turned on.
- This will result in output voltage becomes positive. The cycle completes in this way. The output frequency (from figure B)
  $f_0 = 1 / (t_2 – t_1)$ Hz
- The output frequency of the cyclo converter f_0 is always greater than the supply or input frequency.

Step-down cycloconverter is a device which steps down the fixed frequency power supply input into some lower frequency. It is a frequency changer. If f_s & f_o are the supply and output frequency, then $f_o < f_s$ for this cycloconverter.

The most important feature of step-down cycloconverter is that it does not require force commutation. Line or Natural Commutation is used which is provided by the input AC supply.

Video Content / Details of website for further learning (if any):

- https://subjects.ee.unsw.edu.au/elec4614/Lecture%2019%20-%20three phase%20squarewave%20voltage regulator.pdf

Important Books/Journals for further learning including the page nos.: 246-248

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L43

LECTURE HANDOUTS

EEE | **III / V**

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit V : AC to AC Converters **Date of Lecture:**

Topic of Lecture:

Principle of operation of single phase to single phase cycloconverter

Introduction :

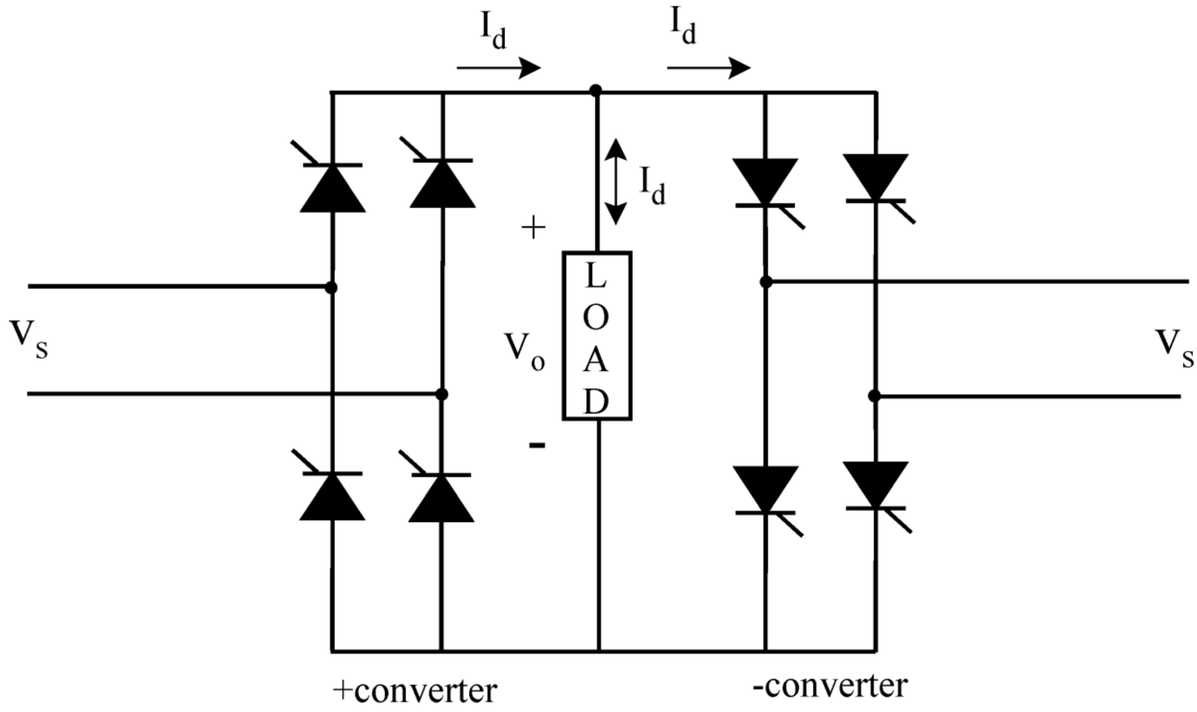
- In industrial applications, two forms of electrical energy are used: direct current (dc) and alternating current (ac). Usually constant voltage constant frequency single-phase or three-phase ac is readily available.
- However, for different applications, different forms, magnitudes and/or frequencies are required. There are four different conversions between dc and ac power sources.
- These conversions are done by circuits called power converters.

Prerequisite knowledge for Complete understanding and learning of Topic:

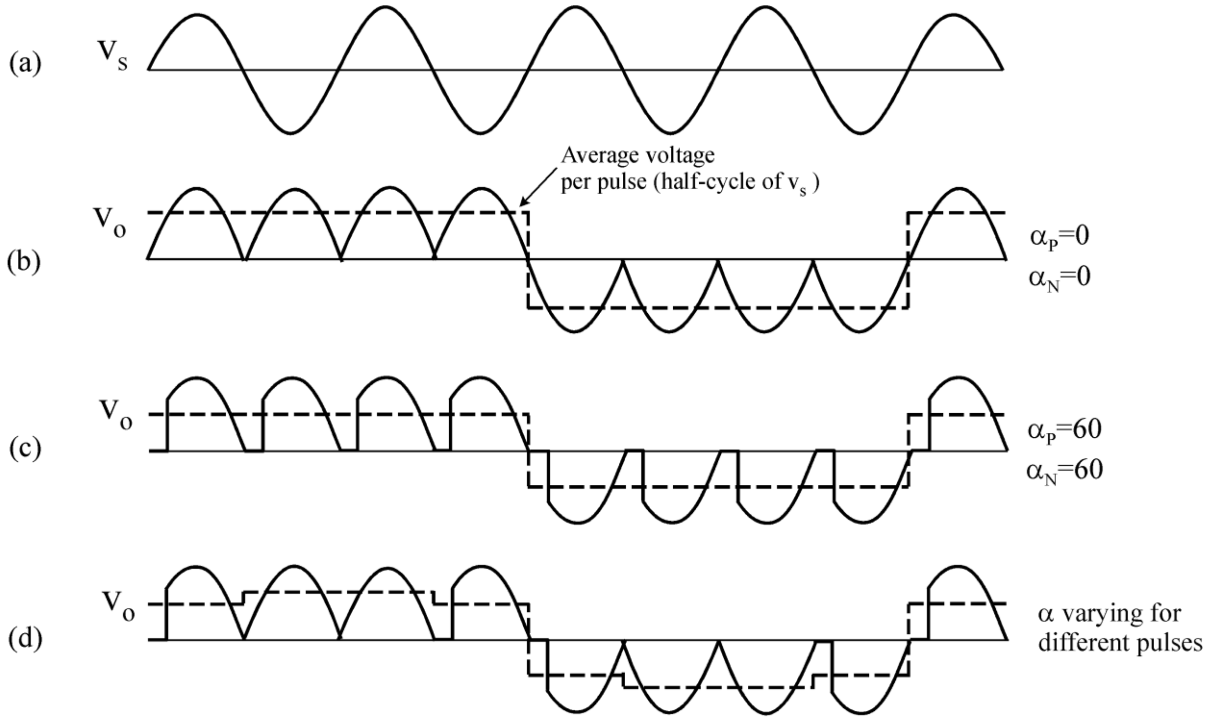
- Converters

Single-phase to Single-phase (1ϕ-1ϕ) Cycloconverter:

- To understand the operation principles of cycloconverters, the single-phase to single-phase cycloconverter should be studied first. This converter consists of back-to-back connection of two full-wave rectifier circuits.
- The input voltage, v_s is an ac voltage at a frequency, f_i as shown in Fig. For easy understanding assume that all the thyristors are fired at $\alpha=0°$ firing angle, i.e. thyristors act like diodes. Note that the firing angles are named as α_P for the positive converter and α_N for the negative converter.
- Consider the operation of the cycloconverter to get one-fourth of the input frequency at the output. For the first two cycles of v_s, the positive converter operates supplying current to the load. It rectifies the input voltage; therefore, the load sees 4 positive half cycles as seen in Fig.
- In the next two cycles, the negative converter operates supplying current to the load in the reverse direction. The current waveforms are not shown in the figures because the resistive load current will have the same waveform as the voltage but only scaled by the resistance.
- Note that when one of the converters operates the other one is disabled, so that there is no current circulating between the two rectifiers.



Single-phase to single-phase cycloconverter



Single-phase to single-phase cycloconverter waveforms

- The frequency of the output voltage, v_o in is 4 times less than that of v_s, the input voltage, i.e. $f_o/f_i=1/4$. Thus, this is a step-down cycloconverter. On the other hand, cycloconverters that have $f_o/f_i>1$ frequency relation are called step-up cycloconverters.
- Note that step-down cycloconverters are more widely used than the step-up ones. The frequency of v_o can be changed by varying the number of cycles the positive and the negative converters work.
- It can only change as integer multiples of f_i in 1ϕ-1ϕ cycloconverters. With the above operation, the 1ϕ-1ϕ cycloconverter can only supply a certain voltage at a certain firing angle α. The dc output of each rectifier is:

$$V_d = \frac{2\sqrt{2}}{\pi} V \cos\alpha$$

where V is the input rms voltage.

Then the peak of the fundamental output voltage is

$$v_{o_1}(t) = \frac{4}{\pi} \frac{2\sqrt{2}}{\pi} V \cos\alpha$$

- Thus varying α, the fundamental output voltage can be controlled. Constant α operation gives a crude output waveform with rich harmonic content.
- If the square wave can be modified to look more like a sine wave, the harmonics would be reduced. Now, the six-stepped dotted line is more like a sinewave with fewer harmonics. The more pulses there are with different α's, the less are the harmonics.

Video Content / Details of website for further learning (if any):

- https://shodhganga.inflibnet.ac.in/bitstream/10603/33606/10/10_chapter5.pdf

Important Books/Journals for further learning including the page nos.: 258-260

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Course Faculty

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit V : AC to AC Converters **Date of Lecture:**

Topic of Lecture:

Principle of operation of single phase to three phase cycloconverter

Introduction :

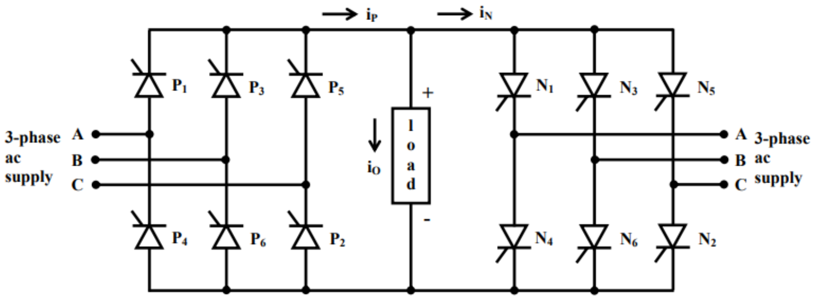
- In industrial applications, two forms of electrical energy are used: direct current (dc) and alternating current (ac). Usually constant voltage constant frequency single-phase or three-phase ac is readily available.
- However, for different applications, different forms, magnitudes and/or frequencies are required. There are four different conversions between dc and ac power sources.
- These conversions are done by circuits called power converters.

Prerequisite knowledge for Complete understanding and learning of Topic:

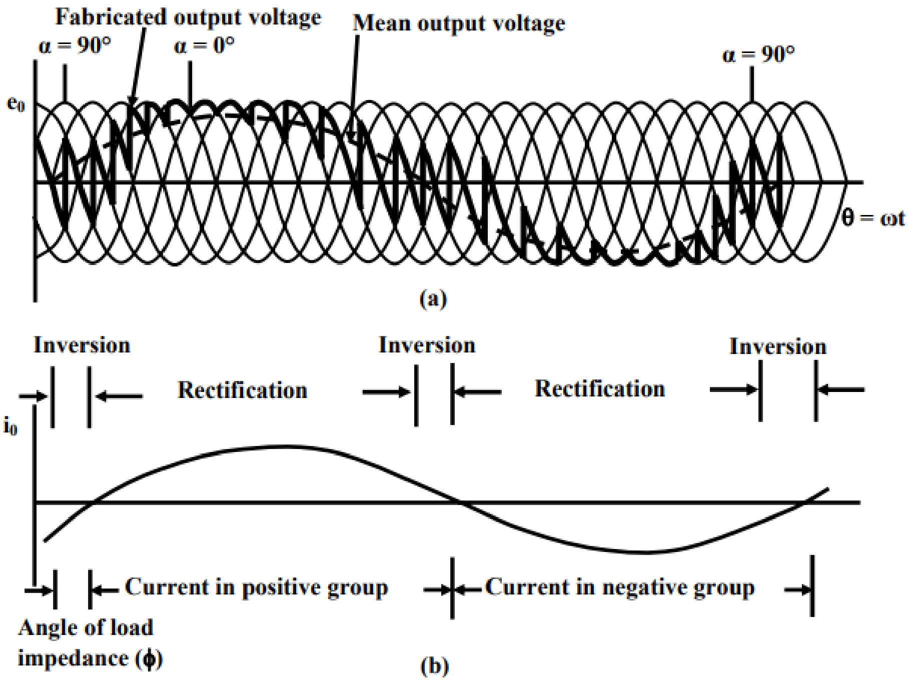
- Converters

Single-phase to Single-phase (1ϕ-3ϕ) Cycloconverter:

- The circuit of a three-phase to single-phase cyclo-converter is shown in Fig. 30.1. Two threephase full-wave (six-pulse) bridge converters (rectifier) connected back to back, with six thyristors for each bridge, are used. The ripple frequency here is 300 Hz, six times the input frequency of 50 Hz. So, low value of load inductance is needed to make the current continuous, as compared to one using single-phase bridge converters described in the previous lesson (#4.4) with ripple frequency of 100 Hz. Also, the non-circulating current mode of operation is used, where only one converter − bridge 1 (positive) or bridge 2 (negative), conducts at a time, but both converters do not conduct at the same time.
- It may be noted that each thyristor conducts for about ° π)3/(120 , i.e., one-third of one complete cycle, whereas a particular thyristor pair, say 1& 2 conduct for about ° π)6/(60 , i.e., one-sixth of a cycle. The thyristors conduct in pairs as stated, one (odd-numbered) thyristor in the top half and the other (even-numbered) one in the bottom half in two different legs. Two thyristors in one leg are not allowed to conduct at a time, which will result in short circuit at the output terminals. The sequence of conduction of the thyristors is 1 & 6, 1 & 2, 3 & 2, and so on. When thyristor 1 is triggered, the conducting thyristor (#5) in top half, being reverse biased at that time, turns off. Similarly, when thyristor 2 is triggered, the conducting thyristor (#6) in bottom half, being reverse biased at that time turns off. This sequence is repeated in cyclic order. So, natural or line commutation takes place in this case.



Single-phase to three-phase cycloconverter



Single-phase to single-phase cycloconverter waveforms

- The procedure to be followed in the triggering of the thyristors in sequence in the two bridge converters has been briefly given earlier. The readers are requested to go through two lessons (#2.5-2.6) in module 2 (AC-DC Converters), or any standard text book. As given in the earlier lesson (#4.4), the firing angle (α) of two converters is first decreased starting from the initial value of to the final value of , and then again increased to the final value of , as shown in Fig. 30.2. Also, for positive half cycle of the output voltage waveform, bridge 1 is used, while bridge 2 is used for negative half cycle. The two half cycles are combined to form one complete cycle of the output voltage, the frequency being decided by the number of half cycles of input voltage waveform used for each half cycle of the output. As more no. of segments of near 90° 0° 90° ° π)6/(60 is used, the output voltage waveform becomes near sinusoidal, with its frequency also being reduced.

Video Content / Details of website for further learning (if any):

- https://shodhganga.inflibnet.ac.in/bitstream/10603/33606/10/10_chapter5.pdf

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L45

EEE

III / V

Course Name with Code : 19EEC07/ Power Electronics

Course Faculty : Dr.R.Sagayaraj

Unit V : AC to AC Converters **Date of Lecture:**

Topic of Lecture:

Matrix converters

Introduction :

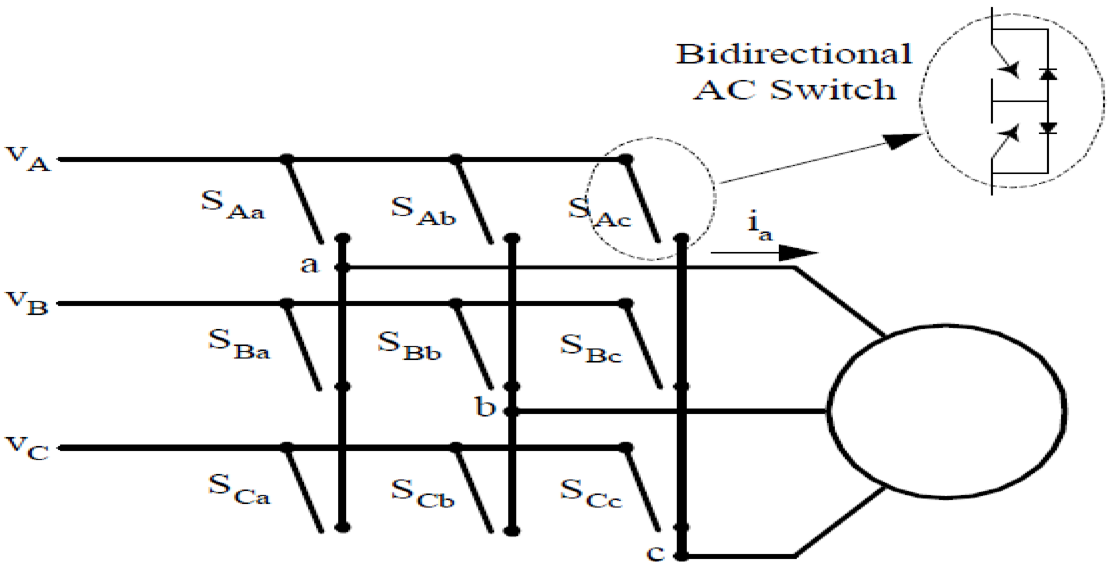
- A matrix converter is defined as a converter with a single stage of conversion. It utilizes bidirectional controlled switch to achieve automatic conversion of power from AC to AC. It provides an alternative to PWM voltage rectifier (double sided).

Prerequisite knowledge for Complete understanding and learning of Topic:

- Basic of real and reactive power
- Converter

Matrix converters

- A matrix converter is defined as a converter with a single stage of conversion. It utilizes bidirectional controlled switch to achieve automatic conversion of power from AC to AC. It provides an alternative to PWM voltage rectifier (double sided).

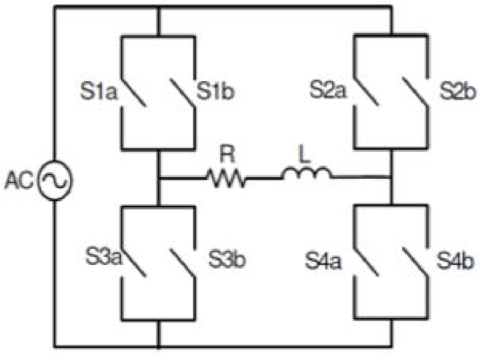


- Matrix converters are characterized by sinusoidal waveforms that show the input and output switching frequencies. The bidirectional switches make it possible to have a controllable power factor input.
- In addition, the lack of DC links ensures it has a compact design. The downside to matrix converters is that they lack bilateral switches that are fully controlled and able to operate at high frequencies. Its voltage ratio that is output to input voltage is limited.

There are three methods of matrix converter control

- Space vector modulation
- Pulse width modulation
- Venturi - analysis of function transfer

The diagram given below shows a single-phase matrix converter.



- It contains four bi-directional switches with each switch having the ability to conduct in both forward blocking and reverse voltage.

Space Vector Modulation (SVM)

- SVM refers to a method of algorithm used to control the PWM. It creates AC waveforms that drive AC motors at various speeds. In the case of a three-phase inverter having DC supply power, its three main legs at the output are connected to a 3-phase motor.
- The switches are under control to ensure that no two switches in the same leg are ON at the same time. Simultaneous ON states could result in the DC supply shorting. This leads to eight switching vectors where two are zero and six are active vectors for switching.

Video Content / Details of website for further learning (if any):

- www.nptel.ac.in/courses/108104052/26

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