INDUSTRIAL AUTOMATION

COURSE CODE: 5042 (REV 2021)

RECTIFIERS, INVERTERS, CYCLO CONVERTERS, CHOPPERS

MODULE II NOTES

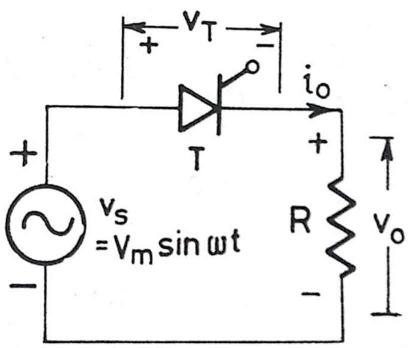
Prepared by,
Najla Pary
Lecturer in Electronics
GPC Perinthalmanna

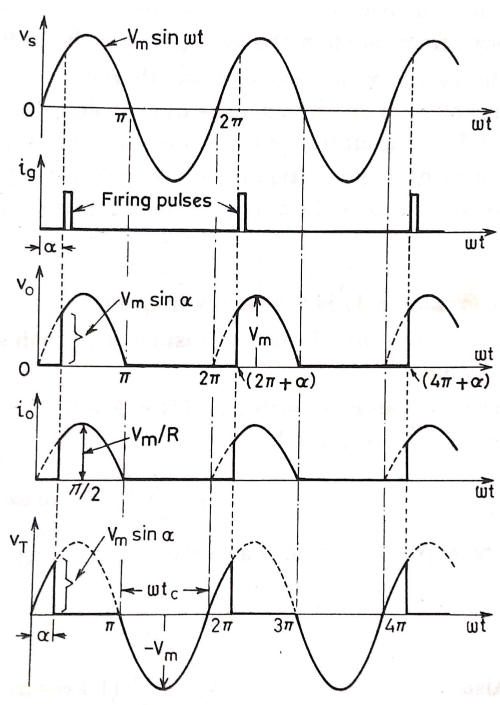
SINGLE PHASE CONVERTERS (CONTROLLED RECTIFIERS)

Phase controlled rectifiers or converters are AC to DC converters which uses thyristors. Constant AC input voltage is converted to controlled DC output voltage. When AC supply is used, the supply voltage reverse biases the thyristor during negative half cycle when anode current is less than the holding current. This turns SCR OFF and thus line commutation is used in phase-controlled rectifiers. Hence there is no need of external circuitry for commutation. These circuits are widely used in industries where controlled DC power is required.

In phase-controlled rectifiers circuits discussed here, it is assumed that there is no voltage drop across SCR when it is ON, holding current is zero and that there is no reverse leakage current when reverse voltage is applied. Also, triggering circuits are not shown for convenience.

Single phase Half Wave controlled rectifier with R (Resistive) load.



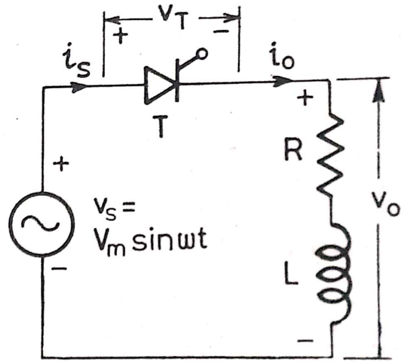


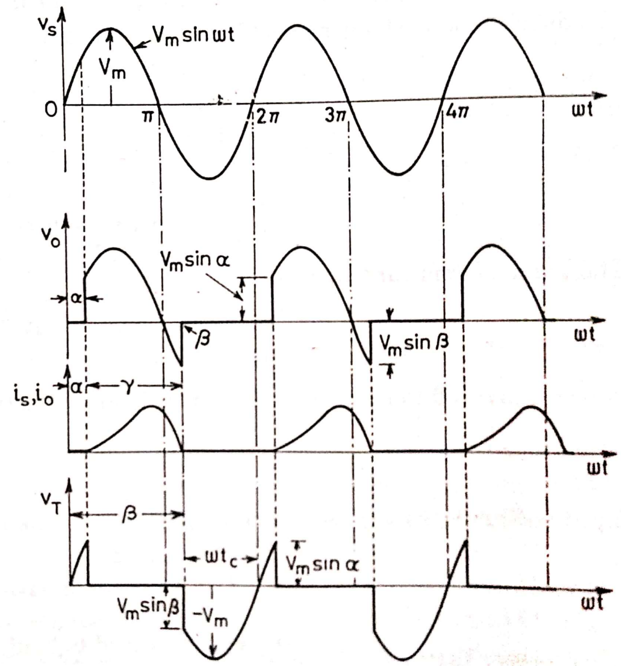
In this circuit, input voltage is $V_S = V_m \sin \omega t$. During positive half cycle, when SCR is turned ON at a firing angle α, current flows through the circuit and input voltage is available at the output across the load. Since the load is resistive, the load current waveform will follow the shape of output voltage. The peak load current will be Vm/R.

During negative half cycle, SCR gets reverse biased and is turned OFF. Output voltage will be zero and the entire input voltage will drop across SCR. In single phase half wave controlled rectifier, there is only one pulse of current during one cycle of the source voltage.

Firing angle: Firing angle is defined as the angle measured from the instant the SCR gets forward biased, to the instant it is triggered and turned ON.

Single phase Half Wave controlled rectifier with RL load



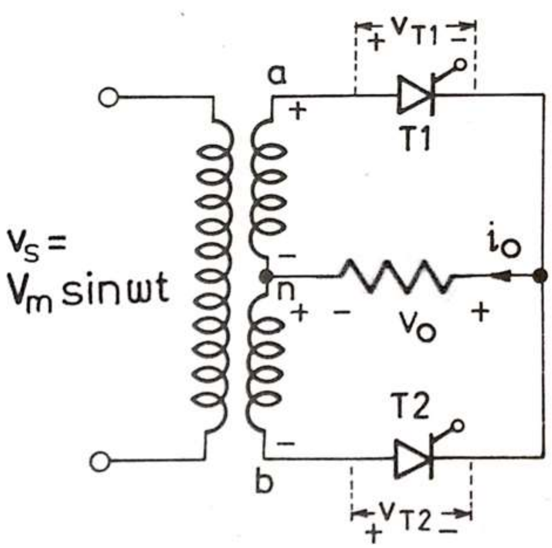


In this circuit, input voltage is $V_S = V_m \sin \omega t$. During positive half cycle, when SCR is turned ON at a firing angle α, current flows through the circuit and supply voltage is available at the output across the load. Since the load has inductor, the load current can rise only gradually. After some time, i_o reaches maximum, then decreases.

At ωt=π, i_o is not zero. During negative half cycle, SCR is reverse biased, but it is not turned OFF, because there is still current flowing through the load, due to the presence of inductor.

At ωt=β, i_o becomes zero and SCR is turned OFF. The angle β at which an SCR turns OFF is known as the **extinction angle**. β -α is known as the **conduction angle.**

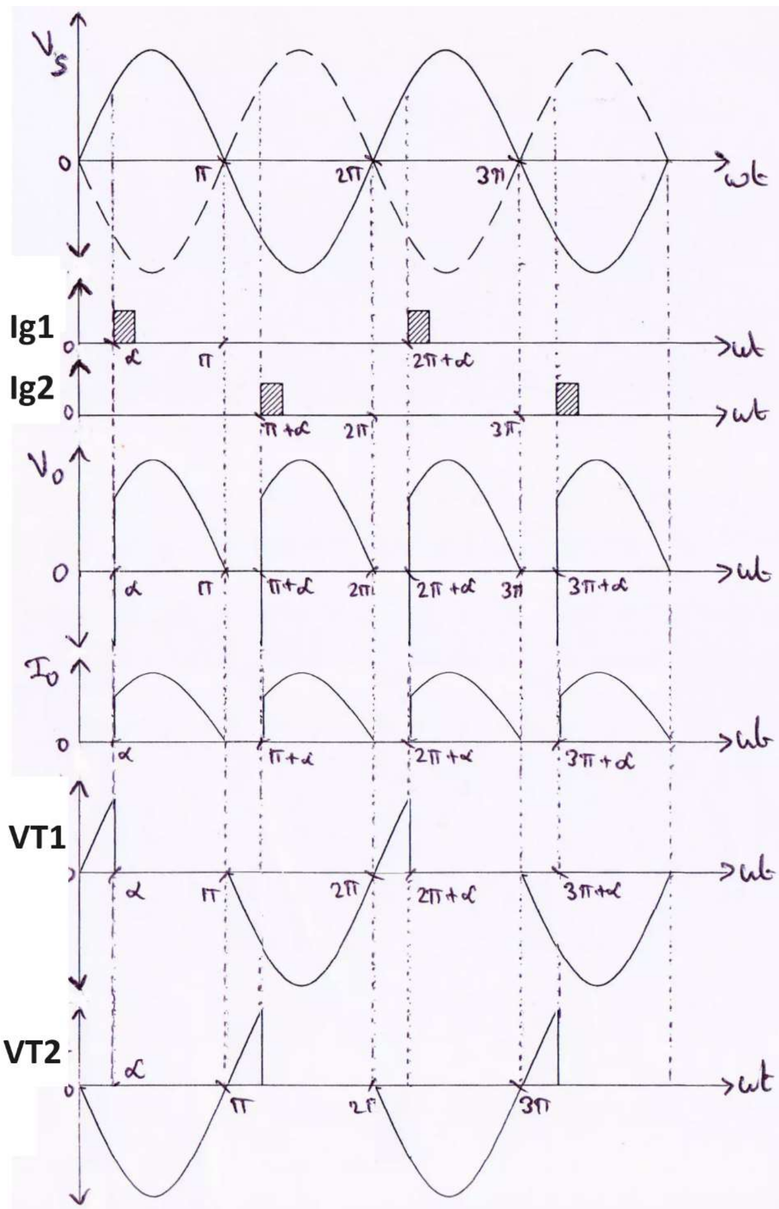
Single phase Full Wave midpoint converter with R (Resistive) load.



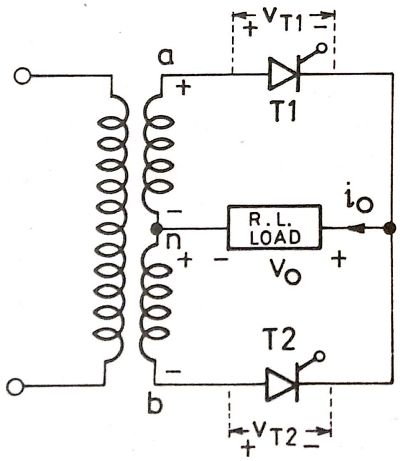
In this circuit, input voltage is $V_S = V_m \sin \omega t$. During positive half cycle, T1 is turned ON at a firing angle α. Current flows in the upper loop from point a through T1 to load to point n in the direction as marked. Output voltage will be same as the input voltage when T1 is ON. Since the load is resistive, the load current waveform will follow the shape of output voltage. The peak load current will be Vm/R. During this time T2 is reverse biased.

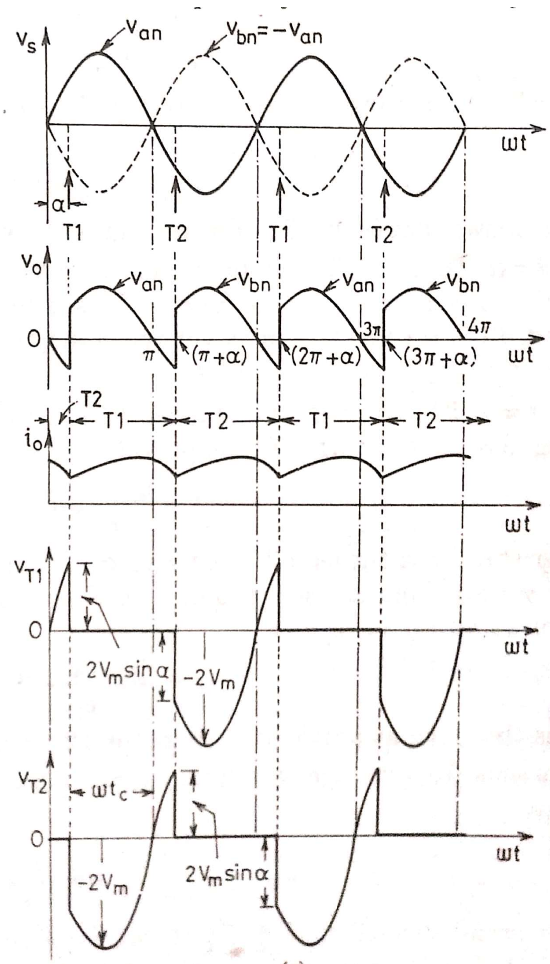
During negative half cycle, T1 is reverse biased and is turned OFF. At a firing angle ωt=π+ α, T2 is turned ON. Current flows in the lower loop from point b through T2 to load to point n in the same direction, as during the positive half cycle. That is the direction of current through the load is the same during both positive and negative half cycles of the input voltage. Thus the output current and output voltage are unidirectional. Output voltage during this time will be the inverse of input voltage.

In single phase full wave midpoint converter, there are two pulses of current during one cycle of the source voltage.



Single phase Full Wave midpoint converter with RL load





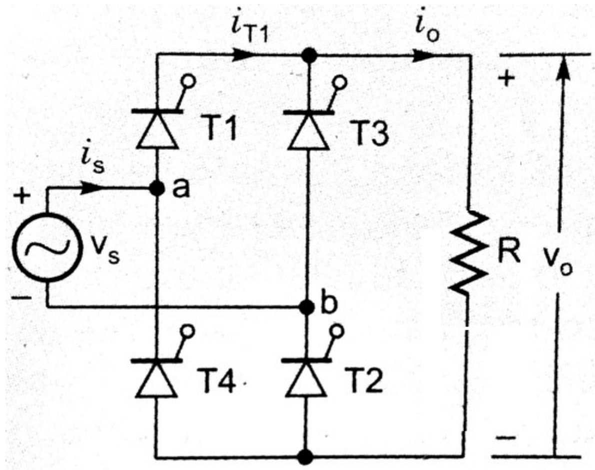
In this circuit, input voltage is $V_S = V_m \sin \omega t$. During positive half cycle, T1 is turned ON at a firing angle α. Current flows in the upper loop from point a through T1 to load to point n in the direction as marked. Output voltage will be same as the input voltage when T1 is ON. During this time T2 is reverse biased.

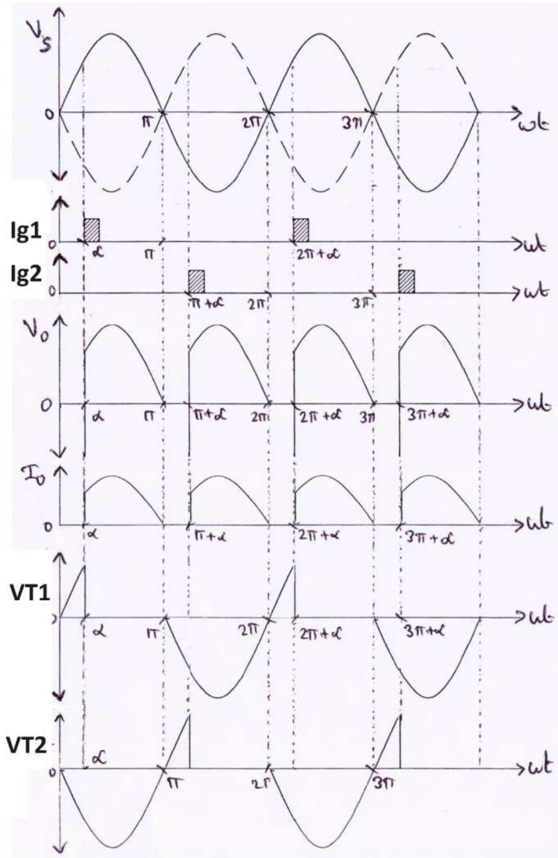
Since the load has inductor, the load current can rise only gradually. After some time, i_o reaches maximum, then decreases. At ωt=π, i_o is not zero. During negative half cycle, T1 is reverse biased, but it is not turned OFF, because there is still current flowing through the load, due to the presence of inductor.

At ωt=, π+ α, T2 is turned ON and T1 becomes OFF. Current flows in the lower loop from point b through T2 to load to point n in the same direction, as during the positive half cycle. That is the direction of current through the load is the same during both positive and negative half cycles of the input voltage. Thus, the output current and output voltage are unidirectional. Output voltage during this time will be the inverse of input voltage. There will be current flow always through the load due to the presence of inductor.

Voltage across the thyristors is also shown in the figure.

Single phase Full Wave bridge converter with R (Resistive) load

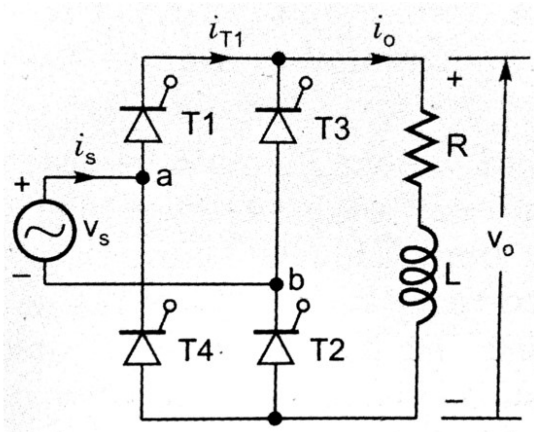


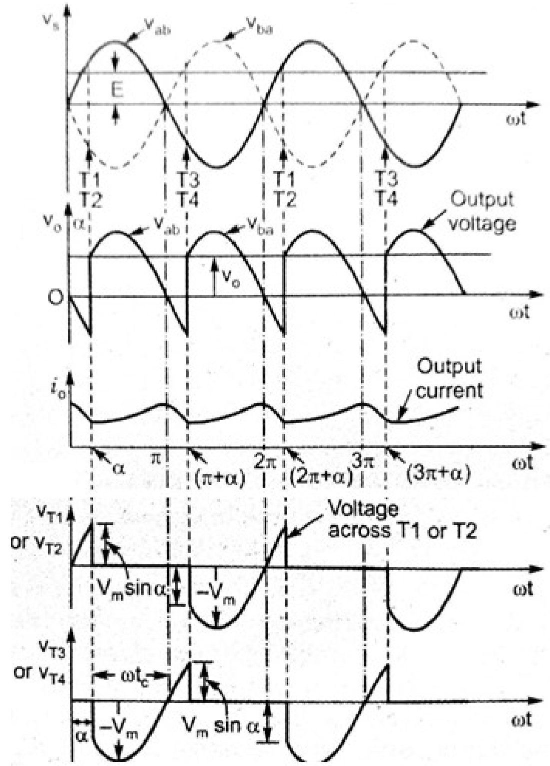


In this circuit, input voltage is $V_S = V_m \sin \omega t$. During positive half cycle, T1 and T2 are turned ON at a firing angle α. Current flows through the circuit from Vs-T1-R-T2-Vs in the direction as marked. Output voltage will be same as the input voltage when T1 and T2 are ON. Since the load is resistive, the load current waveform will follow the shape of output voltage. The peak load current will be Vm/R. During this time T3 and T4 are reverse biased.

During negative half cycle, T1 and T2 are reverse biased and are turned OFF. At a firing angle ωt=π+ α, T3 and T4 are turned ON. Current flows through the circuit from Vs-T3-R-T4-Vs in the same direction, as during the positive half cycle. That is the direction of current through the load is the same during both positive and negative half cycles of the input voltage. Thus, the output current and output voltage are unidirectional. Output voltage during this time will be the inverse of input voltage.

Single phase Full Wave bridge converter with RL load





In this circuit, input voltage is $V_S = V_m \sin \omega t.$ During positive half cycle, T1 and T2 are turned ON at a firing angle α. Current flows through the circuit from Vs-T1-R-T2-Vs in the direction as marked. Output voltage will be same as the input voltage when T1 and T2 are ON. During this time T3 and T4 are reverse biased.

Since the load has inductor, the load current can rise only gradually. After some time, i_o reaches maximum, then decreases. At ωt=π, i_o is not zero. During negative half cycle, T1 and T2 are reverse biased, but they are not turned OFF, because there is still current flowing through the load, due to the presence of inductor.

At a firing angle ωt=π+ α, T3 and T4 are turned ON. T1 and T2 becomes OFF. Current flows through the circuit from Vs-T3-R-T4-Vs in the same direction, as during the positive half cycle. That is the direction of current through the load is the same during both positive and negative half cycles of the input voltage. Thus the output current and output voltage are unidirectional. Output voltage during this time will be the inverse of input voltage.

There will be current flow always through the load due to the presence of inductor. Voltage across the thyristors are also shown in the figure.

Applications of phase controlled rectifiers

Phase controlled rectifiers are used in DC motor drives in paper mills, printing presses and textiles, in traction systems which work on DC, in portable hand tool drives and in electro chemical and electro metallurgical applications.

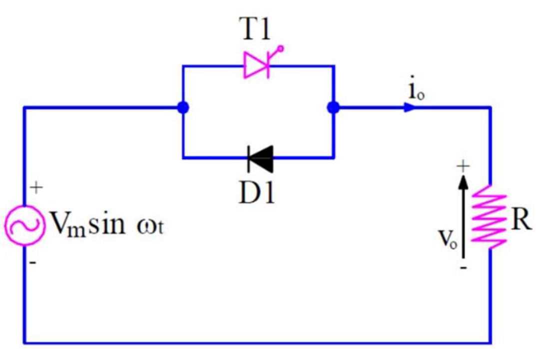
AC Voltage Controllers

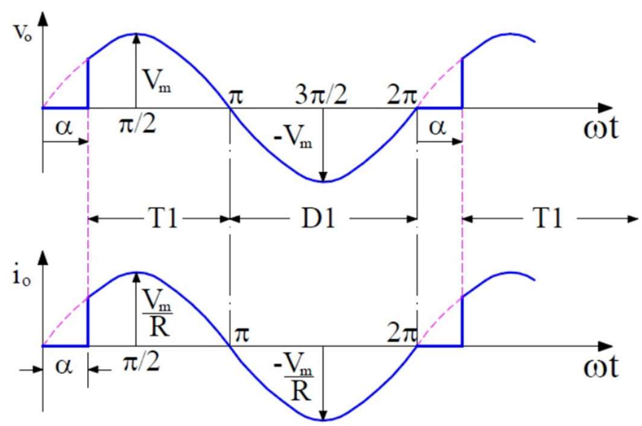
AC Voltage controllers are thyristor-based devices which convert fixed alternating voltage to variable alternating voltage without change in frequency. Some important **applications** are

- Domestic and industrial heating
- Lighting control
- Speed control of single phase and 2 phase drives
- Starting of induction motors

AC Voltage controllers are phase-controlled devices. That means, control of voltage is made possible by controlling the phase of the output voltage, by triggering the thyristor at suitable firing angle. Line commutation is used to turn OFF the thyristors.

Single phase half wave AC Voltage controller using SCR

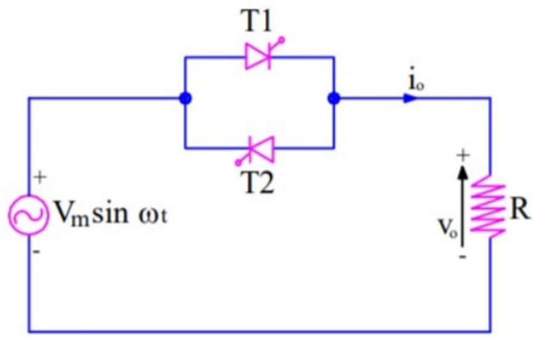


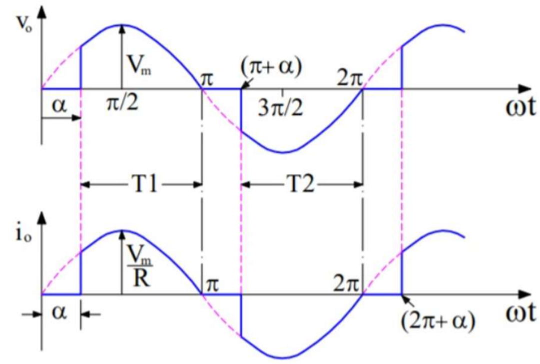


AC Voltage controllers work on the principle of phase control. SCR is operated such that load gets connected with the source for a part of each cycle. Half wave AC voltage control circuit consists of one thyristor in antiparallel with one diode. The thyristor T1 is forward biased during positive half cycle. It turns on when a trigger is given at the gate after the firing angle α. T1 conducts from α to π . Once the SCR is ON load voltage will be same as the source voltage.

During negative half cycle, SCR is turned OFF, but the diode D1 is turned ON. D1 conducts from π to 2π. With half wave AC voltage controller, only positive half cycle can be controlled. Negative half cycle cannot be controlled. Since the load is a resistive load, current waveform will be similar to the voltage waveform.

Single Phase Full Wave AC Voltage Controller using SCR

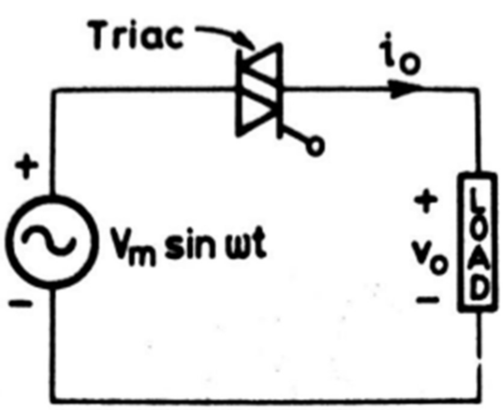


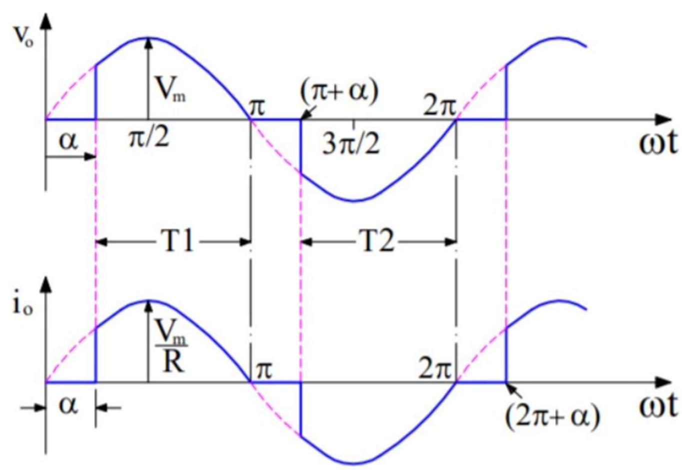


A single phase full wave AC voltage controller comprises of two thyristors connected in anti-parallel. For the positive half cycle of input source, thyristor T1 is forward biased and hence it conducts when gate signal is applied. When T1 conducting and hence, load gets directly connected to the source. From wt = α to π, the load voltage and current follows the input voltage waveform.

During negative half cycle, T1 is reverse biased and it turns OFF. At ωt = (π+α), forward biased thyristor T2 is fired. Hence, it conducts and connects load to the source. The load voltage and current now follows the negative envelop of the AC input supply. Thus, during both the half cycles, only a portion of the input voltage is available at the load. Hence the AC voltage control is done by phase control.

Single-phase full-wave AC voltage controller using Triac





AC Voltage controller using Triac works just like SCR full wave controller. During positive half-cycle, at a firing angle α, triac is triggered. Current i_o flows through triac- load and back to source. If the load is purely resistive, the current falls to zero at $\omega t = \pi$, triac turns off. During negative half-cycle, at $\omega t = (\pi+\alpha)$ triac is again triggered. Triac conducts and current flows through circuit. At $\omega t = 2\pi$ triac turns off and the cycle repeats. When the thyristor is ON and it conducts, the output voltage will follow the source voltage. Thus, during both the half cycles, only a portion of the input voltage is available at the load. Hence the AC voltage control is done by phase control.

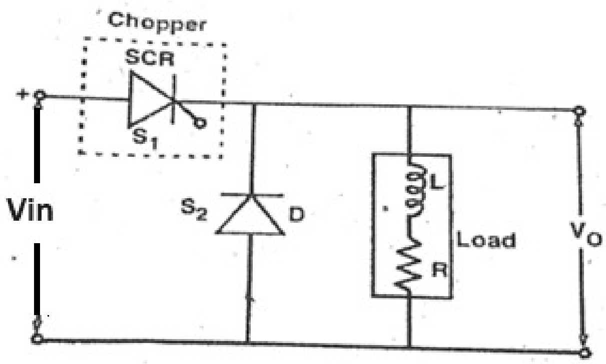
Choppers

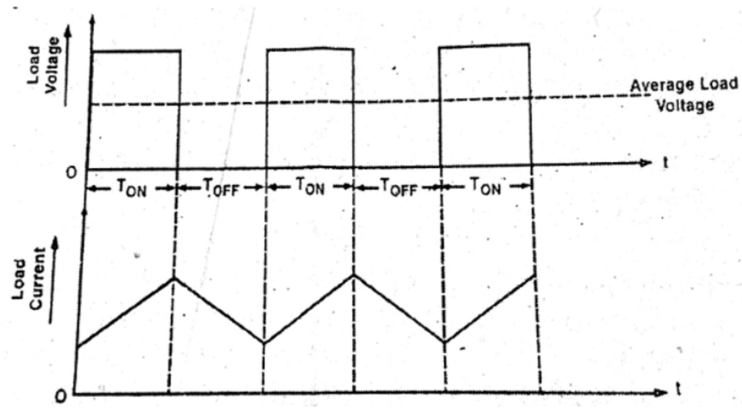
In AC applications, transformers convert electric power from one voltage level to another. In DC to DC converters, the voltage conversion is achieved by power semi conductor devices, which work as static switches at high frequency. Such devices, which convert fixed DC voltage into variable DC voltage are known as choppers. Switching devices like SCR is switched ON and OFF rapidly to chop the input voltage. In this, the input voltage is constant, but the average output DC voltage can be changed.

The voltage conversion ratio of a chopper is defined as $K = \frac{Output\ Voltage}{Input\ Voltage}$.

- If higher input voltage is converted to lower output voltage, it is step down chopper.
  For step down chopper, $K<1$.
- If lower input voltage is converted to higher output voltage, it is step up chopper.
  For step up chopper, $K>1$.

Step down chopper





The chopper shown in figure delivers adjustable DC power into a resistive load from fixed DC voltage source. Load resistance R is connected to the output through an Inductor L. The purpose of this inductor is to smoothen out the fluctuations in the load current, that are caused by the switching process in the chopper. If the inductance L is large, the voltage across load and the current through it will have negligible AC ripple in it.

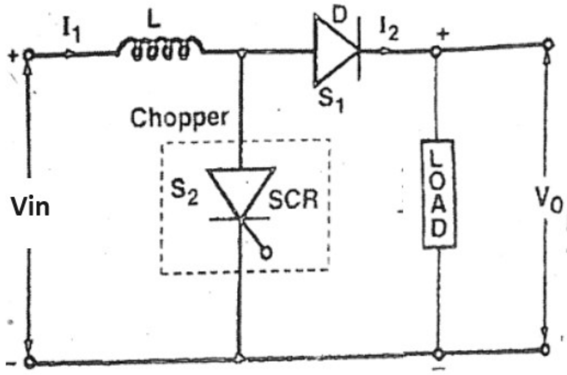
When SCR is turned ON, diode D cannot conduct, because it is reverse biased. Diode will stay OFF. Load current slowly increases due to the presence of inductance. Inductor stores energy during this time. SCR is kept ON for a duration T_{ON}, then turned OFF. When SCR is OFF, current still flows through the load, because the stored energy in the inductor is discharged through the diode. Now current decays through load, inductor and the free-wheeling diode. The output voltage will be zero as the SCR is OFF. This process is repeated by continuously turning ON and OFF the thyristor.

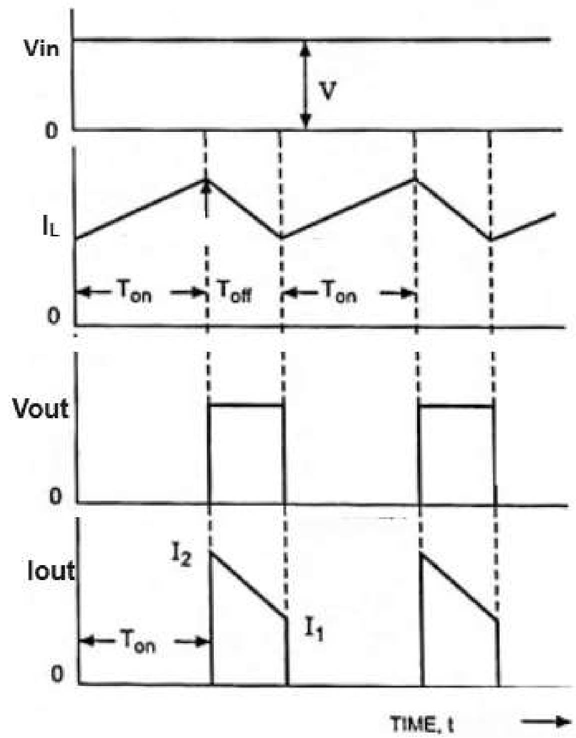
The output voltage is available only during T_{ON} and is given by,

$$V_o = \frac{T_{ON}}{T_{ON} + T_{OFF}} V_{in} = \frac{T_{ON}}{T} V_{in} = Duty\ cycle * V_{in}$$

For step down chopper, the voltage conversion ratio is less than 1.

Step up chopper





The circuit of step-up chopper is shown here.

When the thyristor is ON, inductor charges. There is no current flow through the diode and output voltage and output current will be zero. When the thyristor is turned OFF, current flows through the inductor, diode and load. Since inductor cannot change the direction of current flow through it, it discharges the stored energy through the load. Now the output voltage will be due to two factors. One is the input voltage and the other is due to the release of stored energy of the inductor. Output voltage will be greater than the input voltage, hence the name step-up chopper. When SCR is ON, inductor charges and when SCR is OFF, inductor discharges. Hence the inductor current I_L rises and falls. When the SCR is OFF, load current will be same as I_L.

Output voltage is given by,

$$V_o = \frac{T_{ON} + T_{OFF}}{T_{OFF}} V_{in}$$

The voltage transformation ratio for step-up chopper is greater than 1.

Applications of choppers

1. Speed control of DC series motors in traction systems
2. Speed control of induction motor
3. As regulators in SMPS.
4. Used in Electric Vehicle for smooth acceleration control.