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POWER ELECTRONICS

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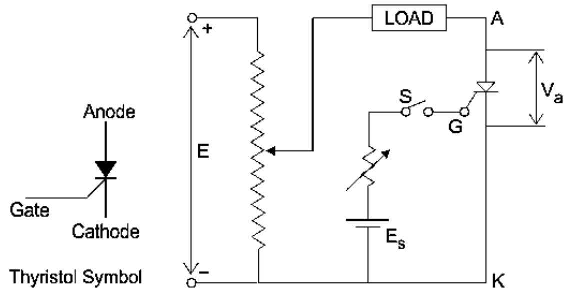
Characteristics of Thyristor or Characteristics of SCR:

A thyristor is a four layer 3 junction p-n-p-n semiconductor device consisting of at least three p-n junctions, functioning as an electrical switch for high power operations. It has three basic terminals, namely the anode, cathode and the gate mounted on the semiconductor layers of the device. The symbolic diagram and the basic circuit diagram for determining the characteristics of thyristor is shown in the figure below:

V-I Characteristics of a Thyristor:



Thyristol Symbol

Circuit Diagram of Thyristor

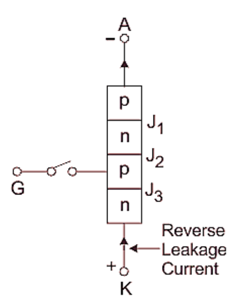
From the circuit diagram above we can see the anode and cathode are connected to the supply voltage through the load. Another secondary supply Es is applied between the gate and the cathode terminal which supplies for the positive gate current when the switch S is closed.

On giving the supply we get the required V-I characteristics of a thyristor show in the figure below for anode to cathode voltage Vaand anode current Ia as we can see from the circuit diagram. A detailed study of the characteristics reveal that the thyristor has three basic modes of operation, namely the reverse blocking mode, forward blocking (off-state) mode and forward conduction (on-state) mode. Which are discussed in great details below, to understand the overall characteristics of a thyristor.

Working Of Thyristor

Reverse Blocking Mode of Thyristor:

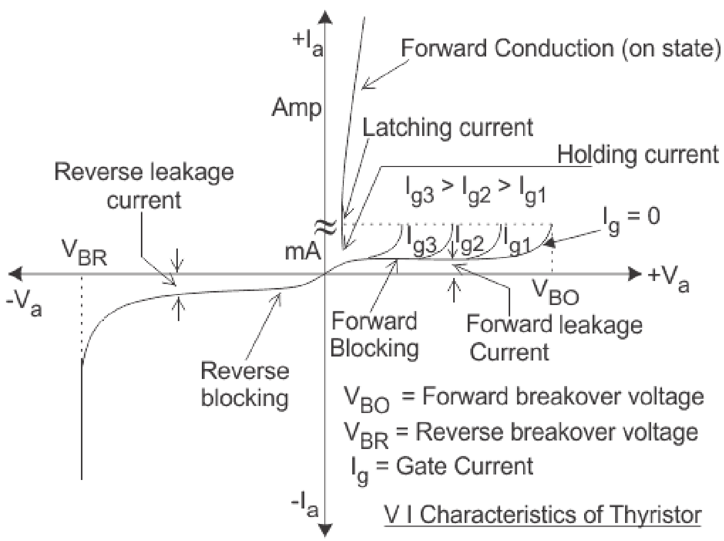
Initially for the reverse blocking mode of the thyristor, the cathode is made positive with respect to anode by supplying voltage E and the gate to cathode supply voltage Es is detached initially by keeping switch S open. For understanding this mode we should look into the fourth quadrant where the thyristor is reverse biased.



Reverse Blocking Mode

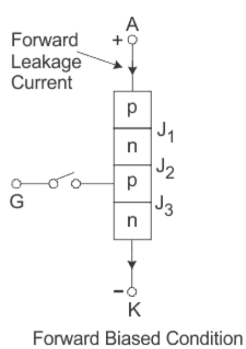
Here Junctions J_1 and J_3 are reverse biased whereas the junction J_2 is forward biased. The behavior of the thyristor here is similar to that of two diodes are connected in series with reverse voltage applied across them. As a result only a small leakage current of the order of a few μAmps flows.

This is the reverse blocking mode or the off-state, of the thyristor. If the reverse voltage is now increased, then at a particular voltage, known as the critical breakdown voltage VBR, an avalanche occurs at J1 and J3 and the reverse current increases rapidly. A large current associated with VBR gives rise to more losses in the SCR, which results in heating. This may lead to thyristor damage as the junction temperature may exceed its permissible temperature rise. It should, therefore, be ensured that maximum working reverse voltage across a thyristor does not exceed VBR. When reverse voltage applied across a thyristor is less than VBR, the device offers very high impedance in the reverse direction. The SCR in the reverse blocking mode may therefore be treated as open circuit.



Forward Blocking Mode:

Now considering the anode is positive with respect to the cathode, with gate kept in open condition. The thyristor is now said to be forward biased as shown the figure below.



As we can see the junctions J1 and J3arenow forward biased but junction J2 goes into reverse biased condition. In this particular mode, a small current, called forward leakage current is allowed to flow initially as shown in the diagram for characteristics of thyristor. Now, if we keep on increasing the forward biased anode to cathode voltage.

In this particular mode, the thyristor conducts currents from anode to cathode with a very small voltage drop across it. A thyristor is brought from forward blocking mode to forward conduction mode by turning it on by exceeding the forward break over voltage or by applying a gate pulse between gate and cathode. In this mode, thyristor is in on-state and behaves like a closed switch. Voltage drop across thyristor in the on state is of the order of 1 to 2 V depending beyond a certain point, then the reverse biased junction J2 will have an avalanche breakdown at a voltage called forward break over voltage VB0 of the thyristor. But, if we keep the forward voltage less than VBO, we can see from the characteristics of thyristor, that the device offers a high impedance. Thus even here the thyristor operates as an open switch during the forward blocking mode.

Forward Conduction Mode:

When the anode to cathode forward voltage is increased, with gate circuit open, the reverse junction J2 will have an avalanche breakdown at forward break over voltage VBO leading to thyristor turn on. Once the thyristor is turned on we can see from the diagram for characteristics of thyristor, that the point M at once shifts toward N and then anywhere between N and K. Here NK represents the forward conduction mode of the thyristor. In this mode of operation, the thyristor conducts maximum current with minimum voltage drop, this is known as the forward conduction forward conduction or the turn on mode of the thyristor.

Applications:

The main application of thyristors is to control high power circuits.

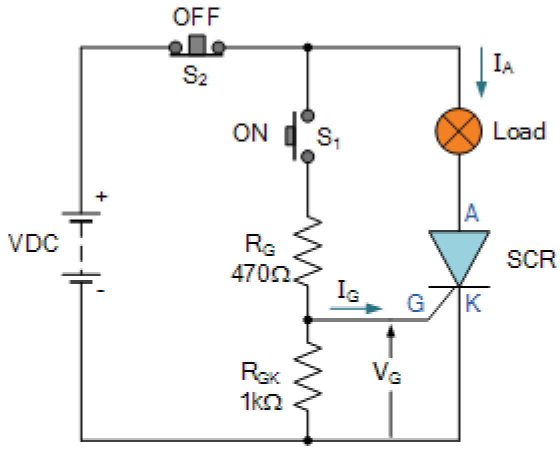
- They find applications in power supplies for digital circuits.
- AC & DC motor speed controllers consist of thyristors.
- A thyristor is also used in light dimmers.

Power Electronics Circuit:

DC Thyristor Circuit:

When connected to a direct current DC supply, the thyristor can be used as a DC switch to control larger DC currents and loads. When using the Thyristor as a switch it behaves like an electronic latch because once activated it remains in the “ON” state until manually reset. Consider the DC thyristor circuit below.

DC Thyristor Switching Circuit:



This simple "on-off" thyristor firing circuit uses the thyristor as a switch to control a lamp, but it could also be used as an on-off control circuit for a motor, heater or some other such DC load. The thyristor is forward biased and is triggered into conduction by briefly closing the normally-open "ON" push button, S1 which connects the Gate terminal to the DC supply via the Gate resistor, RG thus allowing current to flow into the Gate. If the value of RG is set too high with respect to the supply voltage, the thyristor may not trigger.

Once the circuit has been turned-"ON", it self latches and stays "ON" even when the push button is released providing the load current is more than the thyristors latching current. Additional operations of push button, S1 will have no effect on the circuits state as once "latched" the Gate looses all control. The thyristor is now turned fully "ON" (conducting) allowing full load circuit current to flow through the device in the forward direction and back to the battery supply.

One of the main advantages of using a thyristor as a switch in a DC circuit is that it has a very high current gain. The thyristor is a current operated device because a small Gate current can control a much larger Anode current.

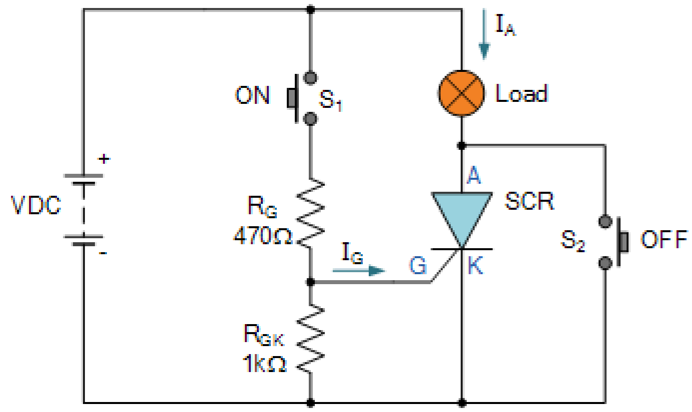
The Gate-cathode resistor RGK is generally included to reduce the Gate's sensitivity and increase its dv/dt capability thus preventing false triggering of the device.

As the thyristor has self latched into the "ON" state, the circuit can only be reset by interrupting the power supply and reducing the Anode current to below the thyristors minimum holding current (IH) value.

Opening the normally-closed "OFF" push button, S2 breaks the circuit, reducing the circuit current flowing through the Thyristor to zero, thus forcing it to turn "OFF" until the application again of another Gate signal.

However, one of the disadvantages of this DC thyristor circuit design is that the mechanical normally-closed "OFF" switch S2 needs to be big enough to handle the circuit power flowing through both the thyristor and the lamp when the contacts are opened. If this is the case we could just replace the thyristor with a large mechanical switch. One way to overcome this problem and reduce the need for a larger more robust "OFF" switch is to connect the switch in parallel with the thyristor as shown.

Alternative DC Thyristor Circuit:

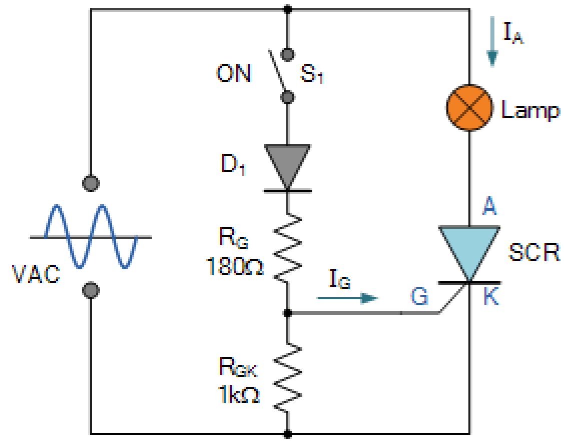


Here the thyristor switch receives the required terminal voltage and Gate pulse signal as before but the larger normally-closed switch of the previous circuit has be replaced by a smaller normally-open switch in parallel with the thyristor. Activation of switch S2 momentarily applies a short circuit between the thyristors Anode and Cathode stopping the device from conducting by reducing the holding current to below its minimum value.

AC Thyristor Circuit:

When connected to an alternating current AC supply, the thyristor behaves differently from the previous DC connected circuit. This is because AC power reverses polarity periodically and therefore any thyristor used in an AC circuit will automatically be reverse-biased causing it to turn-"OFF" during one-half of each cycle. Consider the AC thyristor circuit below.

AC Thyristor Circuit:



The above thyristor firing circuit is similar in design to the DC SCR circuit except for the omission of an additional “OFF” switch and the inclusion of diode D1 which prevents reverse bias being applied to the Gate. During the positive half-cycle of the sinusoidal waveform, the device is forward biased but with switch S1 open, zero gate current is applied to the thyristor and it remains “OFF”. On the negative half-cycle, the device is reverse biased and will remain “OFF” regardless of the condition of switch S1.

If switch S1 is closed, at the beginning of each positive half-cycle the thyristor is fully “OFF” but shortly after there will be sufficient positive trigger voltage and therefore current present at the Gate to turn the thyristor and the lamp “ON”.

The thyristor is now latched-“ON” for the duration of the positive half-cycle and will automatically turn “OFF” again when the positive half-cycle ends and the Anode current falls below the holding current value.

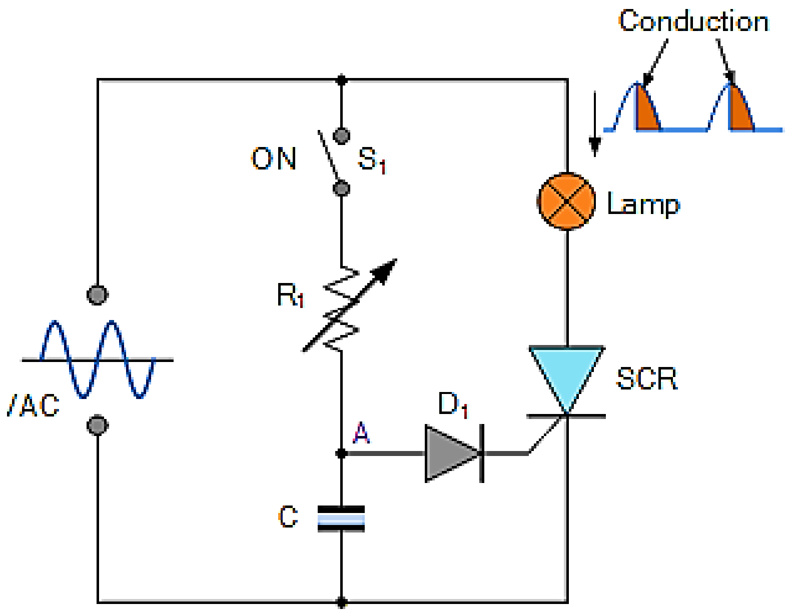
During the next negative half-cycle the device is fully “OFF” anyway until the following positive half-cycle when the process repeats itself and the thyristor conducts again as long as the switch is closed.

Then in this condition the lamp will receive only half of the available power from the AC source as the thyristor acts like a rectifying diode, and conducts current only during the positive half-cycles when it is forward biased. The thyristor continues to supply half power to the lamp until the switch is opened.

If it were possible to rapidly turn switch S1 ON and OFF, so that the thyristor received its Gate signal at the “peak” (90o) point of each positive half-cycle, the device would only conduct for one half of the positive half-cycle. In other words, conduction would only take place during one-half of one-half of a sine wave and this condition would cause the lamp to receive “one-fourth” or a quarter of the total power available from the AC source.

By accurately varying the timing relationship between the Gate pulse and the positive half-cycle, the Thyristor could be made to supply any percentage of power desired to the load, between 0% and 50%. Obviously, using this circuit configuration it cannot supply more than 50% power to the lamp, because it cannot conduct during the negative half-cycles when it is reverse biased. Consider the circuit below.

Half Wave Phase Control:



Phase control is the most common form of thyristor AC power control and a basic AC phase-control circuit can be constructed as shown above. Here the thyristors Gate voltage is derived from the RC charging circuit via the trigger diode, D1.

During the positive half-cycle when the thyristor is forward biased, capacitor, C charges up via resistor R1 following the AC supply voltage. The Gate is activated only when the voltage at point A has risen enough to cause the trigger diode D1, to conduct and the capacitor discharges into the Gate of the thyristor turning it "ON". The time duration in the positive half of the cycle at which conduction starts is controlled by RC time constant set by the variable resistor, R1.

Increasing the value of R1 has the effect of delaying the triggering voltage and current supplied to the thyristors Gate which in turn causes a lag in the devices conduction time. As a result, the fraction of the half-cycle over which the device conducts can be controlled between 0 and 180o, which means that the average power dissipated by the lamp can be adjusted. However, the thyristor is a unidirectional device so only a maximum of 50% power can be supplied during each positive half-cycle.

There are a variety of ways to achieve 100% full-wave AC control using "thyristors". One way is to include a single thyristor within a diode bridge rectifier circuit which converts AC to a unidirectional current through the thyristor while the more common method is to use two thyristors connected in inverse parallel.

Advantages of SCR:

There are some advantages of silicon controlled rectifier (SCR) which are given below,

- The silicon controlled rectifier (SCR) can handle large voltage , current and power.

- It can be protected with the help of fuse.
- It is easy to turn ON.
- The Triggering circuit for silicon controlled rectifier (SCR) is simple.
- It is simple to control.
- It cost is low.
- It is able to control AC power.

Disadvantages of SCR:

There are some disadvantages of silicon controlled rectifier (SCR) which are given below,

- The silicon controlled rectifier (SCR) is unidirectional devices, so it can control power only in DC power during positive half cycle of AC supply. Thus only DC power is controlled with the help of SCR.
- In AC circuit, it needs to be turned on each cycle.
- It cannot be used at higher frequencies.
- The gate current cannot be negative.

Differences Between Diode and Thyristor:

1. A diode is a two-layer device having a p and an n region. While a thyristor is a four-layer semiconductor device formed by alternate arrangement of p and n type material.
2. Due to 2 layers in diode, there exist a single junction in case of diode. Whereas due to 4 layers, the thyristor has 3 junctions.
3. A diode is a 2 terminal device namely anode and cathode. But a thyristor is a 3 terminal device, out of the 3 terminal, 2 are anode and cathode while the other is gate which is used to provide external triggering to the circuit.
4. The power handling ability of thyristors is comparatively better than the diodes.
5. Diodes exhibits low operating voltage nearly about 5000 V. While, the operating voltage is around 7000 V in case of thyristors which is comparatively higher than diodes.
6. Diode is such a device which does not requires external triggering pulse in order to initiate conduction. While thyristor needs external triggering pulse for the circuit operation.
7. Diodes are less costly when compared with thyristors.
8. Thyristors are comparatively bulky than diodes.

From the above discussion we can say that though both diode and thyristor are semiconductor devices. But the operation of the two are quite different thus find applications in different fields.

Also diodes are widely used in rectification circuit, clippers and clampers, logic gates and in voltage multiplier circuits. While thyristors are widely used in high power motors, inverters, in controlled rectification circuits, timing and over voltage protection circuits.

Difference between thyristor and MOSFET:

- In thyristor majority carrier device current-driven device low switching speed low resistive input impedance while in MOSFET majority carrier device voltage driven device high switching speed purely capacitive high input impedance.
- Thyristor has an only single pulse to turn ON but MOSFET has no DC required to maintain conduction expect during turn on and turn off.
- The thyristor can be connected series easily with voltage equalizing circuit whereas in MOSFET series connection is difficult with voltage equalizing circuit.
- The thyristor can be parallel with a forced current sharing circuit while in MOSFET can be easily paralleled due to the positive temperature coefficient of resistance of the device.
- Thyristor has less temperature sensitive, no second breakdown but in MOSFET has too much temperature sensitive, less susceptible to the second breakdown.
- Thyristor has a most robust device, MOSFET has a less robust device.
- Thyristor has a high voltage as well as a high current device while in MOSFET has a high current medium voltage device.
- Thyristor has low on stage voltage drop, MOSFET has a high ON stage voltage drop.

The main difference between thyristor and MOSFET is that thyristor called as SCR is a solid-state semiconductor device with four alternating P and N-type materials while in MOSFET is a metal-based field effect transistor and it most commonly fabricated by the controlled oxidation of silicon side.

Difference between BJT and SCR:

1. BJT has only three layer of semiconductor, whereas SCR has four layers of them.
2. Three terminals of BJT are known as emitter, collector, and base, whereas SCR has terminals known as anode, cathode, and gate
3. SCR is considered as tightly coupled pair of transistors in analysis.

Both BJT (Bipolar Junction Transistor) and SCR (Silicon Controlled Rectifier) are semiconductor devices with alternating P type and N type semiconductor layers. They are used in many switching applications due to many reasons such as efficiency, low cost, and small size. Both of them are three terminal devices, and they provide a good control range of current with a small controlling current. Both these devices have application dependant advantages.

Difference between IGBT and SCR:

Thyristors are 4-layer devices with two sources of carriers in difference with IGBTs. They operate at higher plasma density than 3-layer transistors and have about half the on-state voltage. Higher plasma density means more charge to remove at turn-off, leading to higher turn-off losses. Most thyristors are line commutated so they operate at line frequency and are, for instance, less applicable to variable speed drives.

Inverter:

Inverters are basically used to convert Direct current into Alternating current.This can be achieved by using Thyristor such as SCR, TRIACetc.For single phase inverters, two thyristors (SCRs) are required similar to that of Diode rectifier.

Based on type of connections of semiconductor devices, inverters are classified as under

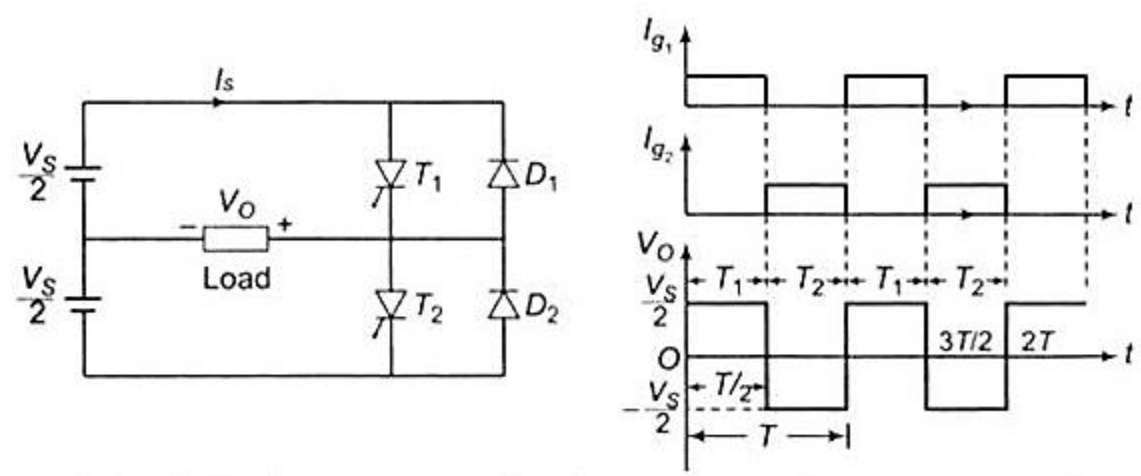
- Series inverter
- Parallel inverter
- Bridge inverter

Single Phase Series Inverter: In a series inverter, the commutating elements L and C are connected in series with the load resistance R. The load resistance R can also be in parallel with C.The value of L and C are such that those form an underdamped circuit.

Single Phase Parallel Inverter: During the working of this inverter, capacitor C comes in parallel with the load via the transformer, so this inverter is called a parallel inverter.

Single Phase Bridge Inverter: Bridge circuits are commonly used in DC-AC conversion. Moreover, an output transformer is not essential in a bridge circuit.

Circuit Diagram:



1-ϕ half bridge inverter　　Waveforms of gate pulses and output voltage

Construction of circuit:-

Basically, for single phase half bridge inverter as shown in fig, the following components are required:-

- Two thyristors

- Load
- One voltage source (divided in two sources)
- Two diodes.

Operation:-

1. A single DC source is divided into two DC Sources.
2. Initially, two thyristors are not triggered to turn 'ON', so zero current flows through the device.
3. The Thyristor T1 is turned 'ON' by giving a gate pulse it. The Thyristor T2 is kept 'OFF' and no gate signal is given to it.
4. Thus, the ThyristorT1 starts conducting and the current starts to flow from Edc/2(positive terminal of 1st source)-T1-Load-negative terminal of 1st source.
5. Thus, a positive cycle similar to that of ac cycle is obtained.
6. Now, the Thyristor T1 is made 'OFF' and T2is made 'ON' by giving a gate signal to it.
7. The Thyristor T2 starts to conduct and the current starts to flow through the load.
8. The current takes the following path:-
   Edc/2 positive terminal of 2nd source)-Load-T2-negative terminal of the 2ndsource.
9. Thus, a negative cycle is produced.
10. Two SCRs are triggered alternatively so that the load conducts current in both directions.
11. Thus, a square ac wave is generated.
12. Hence, direct current is converted into alternating current using inverter circuit.

Uses:-

- DC power source usage
- Uninterruptible power supplies
- In refrigeration compressor
- Portable consumer devices that allow the user to connect a battery, or set of batteries, to the device to produce AC power to run various electrical items such as lights, televisions, kitchen appliances, and power tools.
- Use in power generation systems such as electric utility companies or solar generating systems to convert DC power to AC power.
- Use within any larger electronic system where an engineering need exists for deriving an AC source from a DC source.

The simulation of the open-loop three-phase inverter is illustrated:

The list of configuration parameters used is:

Start time: 0	Stop time: 1.5
Type: Variable−step	Solver: ode15s (stiff/NDF)
Max step size: 1e−5	Relative tolerance: 1e−3
Min step size: auto	absolute tolerance: auto

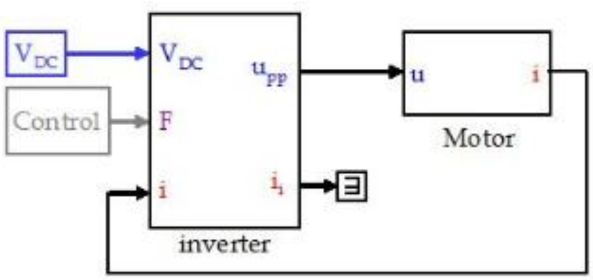
The relation between the amplitude of the sinusoidal voltage and the triangular voltage determines the maximum value of the fundamental line-line voltage of the inverter:

$$U_{\max} = \frac{\sqrt{3}}{2}\,\frac{V_{m\max}}{V_{t\max}}\,V_{DC} = \frac{\sqrt{3}}{2}\,\frac{0.5}{1}\,400 = 173\,V$$

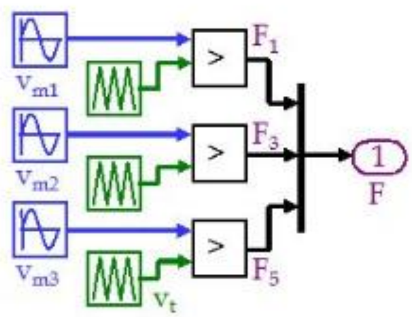
Neglecting the current harmonics, the maximum value of the line current is deduced from equation

$$I_{1\max} = \sqrt{3}\,J_{12\max} = \frac{\sqrt{3}\,.\,U_{\max}}{\sqrt{R_M^{\,2} + (L_M 2\pi f_m)^2}} = \frac{\sqrt{3}\,.\,173}{\sqrt{4^2 + (10^{-2}\,2\pi\,50)^2}} = 59\,A$$

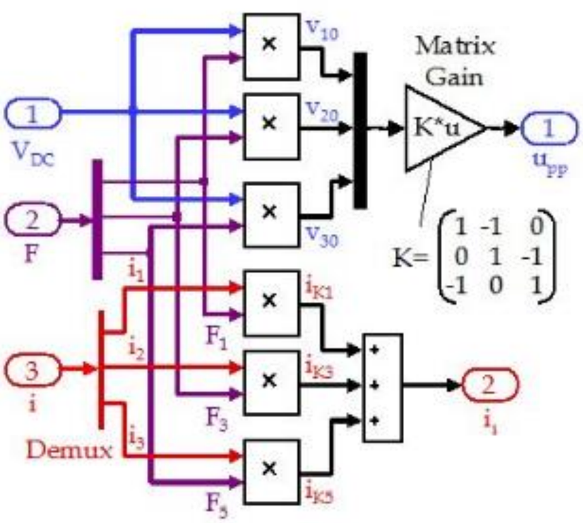
Simulations are in good agreement with theoretical values.



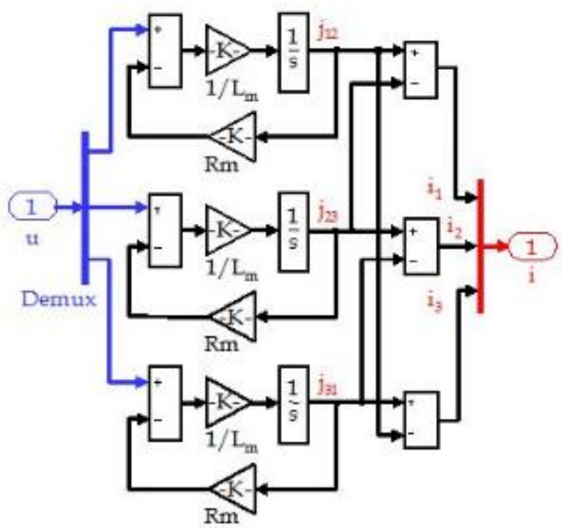
a) Global view



b) Control block

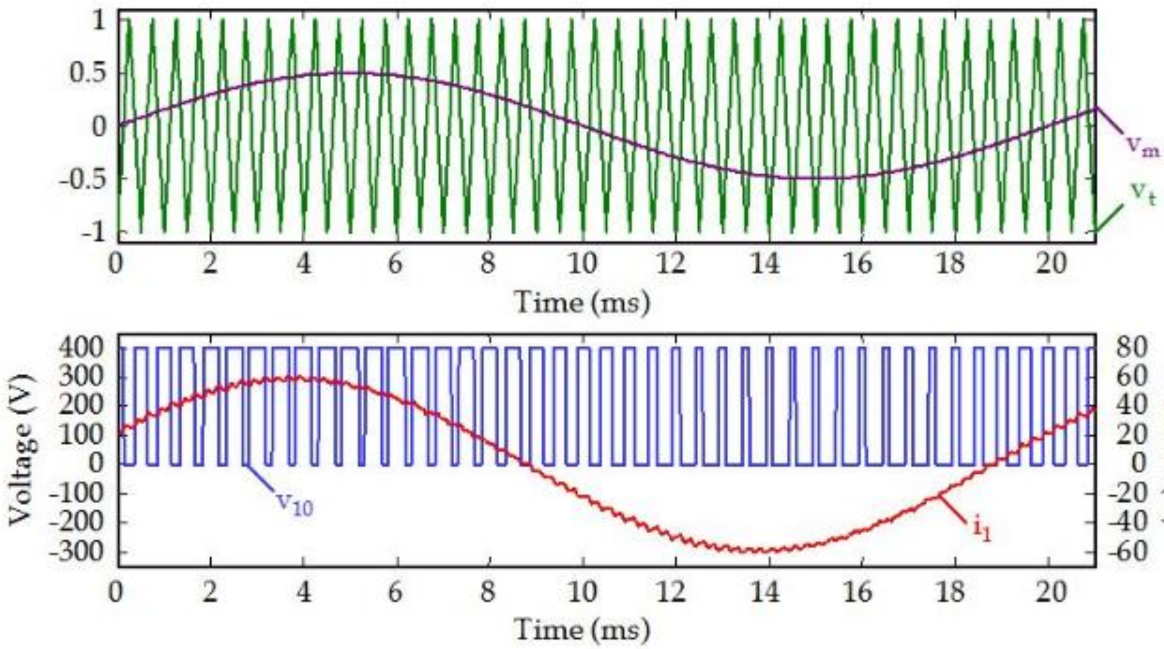


c) Inverter Block



d) Motor block

Output:



Conclusion:

In this project we achieved the required speed and thyristor is a very good device for obtaining the variable DC there by controlling the motor speed. In the above circuits are just basic circuits for understanding DC motor speed control. In case of HWR we got zero voltage in negative half cycle that's why has power efficiency.