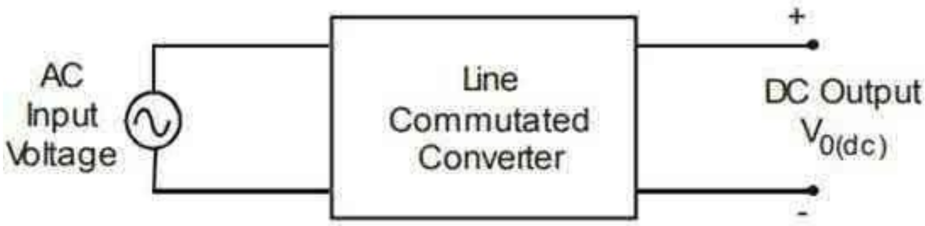
# EE6009 POWER ELECTRONICS FOR RENEWABLE ENERGY SYSTEMS
# UNIT III - POWER CONVERTERS AND ANALYSISOF SOLAR PV SYSTEMS
# 3.2 - SIMULATION OF LINE COMMUTATED CONVERTERS, BUCK/BOOST CONVERTERS.

## LINE COMMUTATED CONVERTERS

### Introduction to Controlled Rectifiers

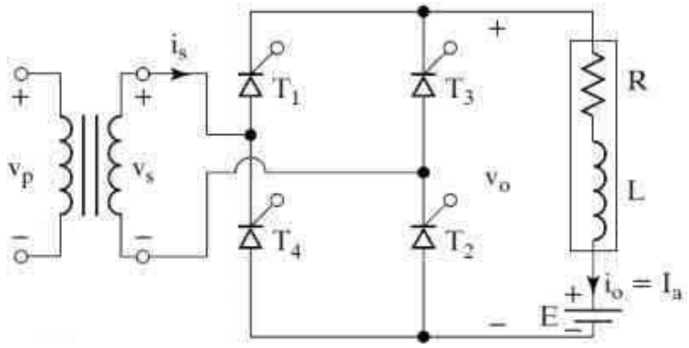



Controlled rectifiers are line commutated ac to dc power converters which are used to convert a fixed voltage, fixed frequency ac power supply into variable dc output voltage. Type of input: Fixed voltage, fixed frequency ac power supply. Type of output: Variable dc output voltage. The input supply fed to a controlled rectifier is ac supply at a fixed RMS voltage and at a fixed frequency. We can obtain variable dc output voltage by using controlled rectifiers. By employing phase controlled thyristors in the controlled rectifier circuits we can obtain variable dc output voltage and variable dc (average) output current by varying the trigger angle (phase angle) at which the thyristors are triggered. There are several types of power converters which use ac line commutation. These are referred to as line commutated converters.

### Line commutated converters under inversion mode

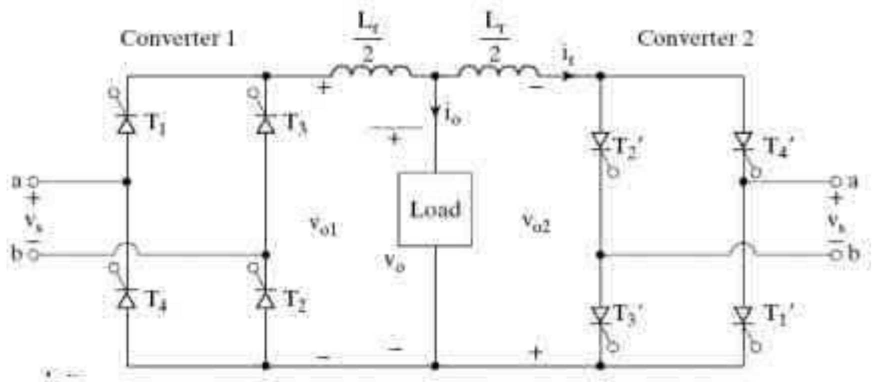
**Single Phase Full Converter**

The circuit diagram of a single phase fully controlled bridge converter is shown in the figure with a highly inductive load and a dc source in the load circuit so that the load current is continuous and ripple free (constant load current operation). The fully controlled bridge converter consists of four thyristors $T_1$, $T_2$, $T_3$ and $T_4$ connected in the form of full wave bridge configuration as shown in the figure. Each thyristor is controlled and turned on by its gating signal and naturally turns off when a reverse voltage appears across it. During the positive half cycle when the upper line of the transformer secondary winding is at a positive potential with respect to the lower end the thyristors $T_1$ and $T_2$ are forward biased during the time interval $\omega t$ = 0 to $\pi$ . As soon as the thyristors $T_3$ and $T_4$ are triggered a reverse voltage appears across the thyristors $T_1$ and $T_2$ and they naturally turn-off and the load current is transferred from $T_1$ and $T_2$ to the thyristors $T_3$ and $T_4$.




**Single Phase Dual Converter**

The dual converter system will provide four quadrant operation and is normally used in high power industrial variable speed drives. The converter number 1 provides a positive dc output voltage and a positive dc load current, when operated in the rectification mode. The converter number 2 provides a negative dc output voltage and a negative dc load current when operated in the rectification mode. We can thus have bidirectional load current and bi-directional dc output voltage. The magnitude of output dc load voltage and the dc load current can be controlled by varying the trigger angles of the converters 1 and 2 respectively. There are two modes of operations possible for a dual converter system like non circulating current mode of operation and circulating current mode of operation.

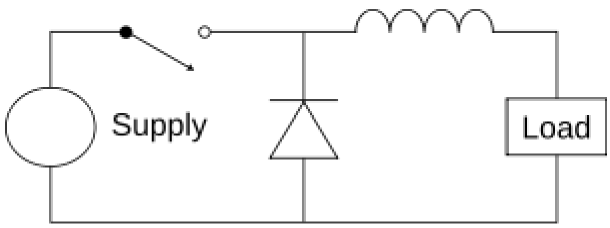



DC-DC Converters

**DC-DC Buck Converter**

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

of switched-mode power supply (SMPS) typically containing at least two semi conductors and at least one energy storage element, a capacitor, inductor, or the two in combination. To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors) are normally added to such a converter's output (load-side filter) and input (supply-side filter).

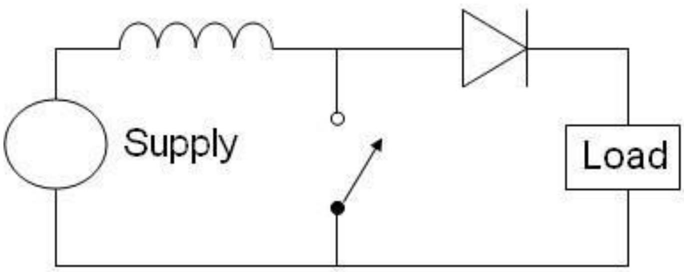



**Buck converter circuit diagram.**

The basic operation of the buck converter has the current in an inductor controlled by two switches. In the idealized converter, all the components are considered to be perfect. Specifically, the switch and the diode have zero voltage drop when on and zero current flow when off, and the inductor has zero series resistance.

**DC-DC Boost Converters**

A boost converter (step-up converter) is a DC-to-DC power converter that steps up voltage (while stepping down current) from its input (supply) to its output (load). It is a class of switched-mode power supply (SMPS) containing at least two semiconductors (a diode and a transistor) and at least one energy storage element: a capacitor, inductor, or the two in combination. To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors) are normally added to such a converter's output (load-side filter) and input (supply-side filter).

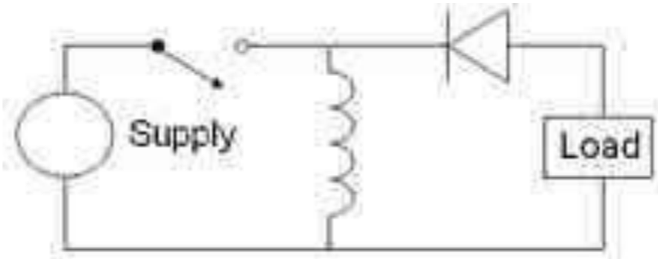



**Basic schematic of a boost converter**

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current by creating and destroying a magnetic field. In a boost converter, the output voltage is always higher than the input voltage. When the switch is closed, current flows through the inductor in clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive. When the switch is opened, current will be reduced as the impedance is higher. The magnetic field previously created will be destroyed to maintain the current towards the load. Thus the polarity will be reversed (means left side of inductor will be negative now). As a result, two sources will be in series causing a higher voltage to charge the capacitor through the diode D.

## DC-DC Buck-Boost Converters

A Buck-Boost converter is a type of switched mode power supply that combines the principles of the Buck Converter and the Boost converter in a single circuit. Like other SMPS designs, it provides a regulated DC output voltage from either an AC or a DC input.




**Buck-Boost Converters**

It is equivalent to a fly-back 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, do wn to almost zero.

## Modes of Buck Boost Converters

There are two different types of modes in the buck boost converter. The following are the two different types of buck boost converters.

- Continuous conduction mode.
- Discontinuous conduction mode.

***Continuous Conduction Mode***

In the continuous conduction mode the current from end to end of inductor never goes to zero. Hence the inductor partially discharges earlier than the switching cycle.

***Discontinuous Conduction Mode***

In this mode the current through the inductor goes to zero. Hence the inductor will totally discharge at the end of switching cycles.

***Applications of Buck boost converter***

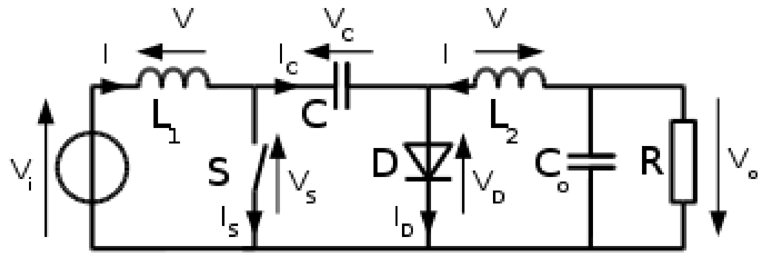
- It is used in the self regulating power supplies.
- It has consumer electronics.
- It is used in the Battery power systems.
- Power amplifier applications.

***Advantages of Buck Boost Converter***

- It gives higher output voltage.

- Low operating duct cycle.

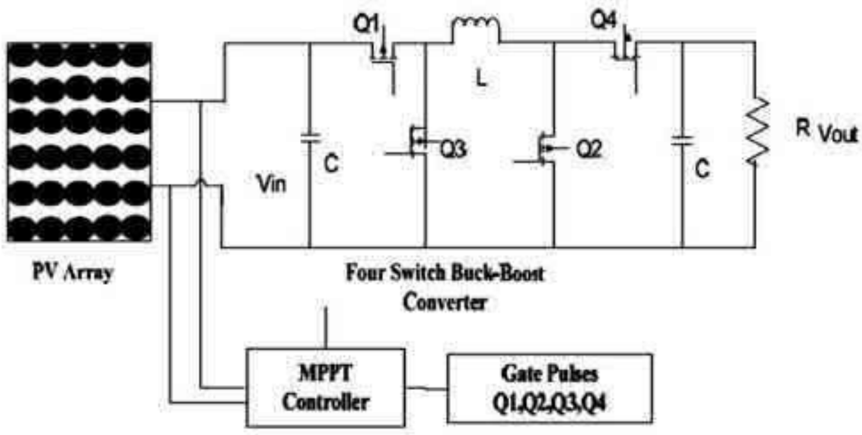
## Cuk converter




**Schematic of a non-isolated Cuk converter**

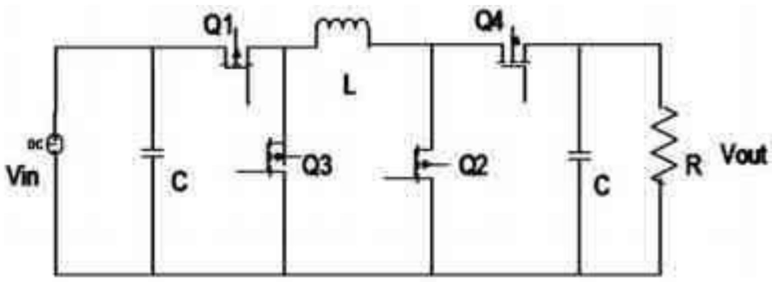
The Cuk converter is a type of DC/DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. It is essentially a boost converter followed by a buck converter with a capacitor to couple the energy. Similar to the buck–boost converter with inverting topology, the output voltage of non-isolated Cuk is typically also inverting, and can be lower or higher than the input. It uses a capacitor as its main energy-storage component, unlike most other types of converters which use an inductor. There are variations on the basic Cuk converter. For example, the coils may share single magnetic core, which drops the output ripple, and adds efficiency. Because the power transfer flows continuously via the capacitor, this type of switcher has minimized EMI radiation. The Cuk converter allows energy to flow bi-directionally by using a diode and a switch.

PV fed Buck Boost Converter (Four switched topology)

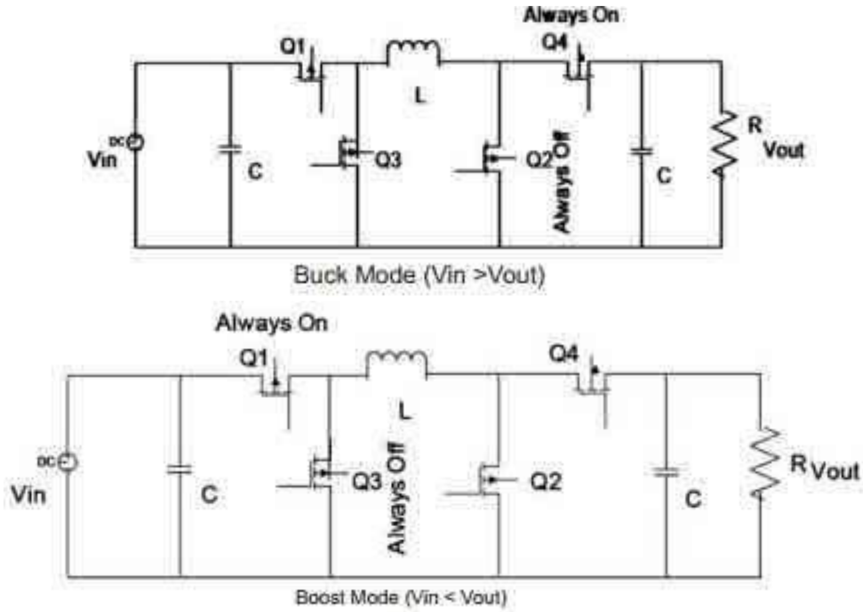



Four-switch power converter is cascaded combination of Buck converter followed by a Boost converter the converter is different from the other DC-DC converters why, because it has four switches to be controlled, that is, two gate pulses we need. This means for the same working point with different values both gate pulses can be used. Furthermore, due to its simple and cascaded combination of Buck-Boost structure, it presents high adaptability and high performance to system voltage changes.

The configuration of the system consists of the Solar PV array fed to FSBB Converter which feeds the Load. It is a combination of Buck converter followed by Boost converter; a four switch buck-boost converter can operate in buck mode or boost mode rather than conventional buck-boost converter. As such, its efficiency can be improved by synchronous rectification the power stage consist of four switches ($Q_1$, $Q_2$, $Q_3$, and $Q_4$), single inductor (L), and input and output Capacitors.




**Four-switch buck-boost converter.**




**Equivalent circuit in Buck/Boost mode**

Here the MOSFETs $Q_3$,$Q_4$ share the gate control signal, which is complementary to the gate control signal of MOSFETs $Q_1$ and $Q_2$, In the buck-boost mode the MOSFETs $Q_1$ and $Q_2$ share gate control signals and turn on and off simultaneously. When the MOSFETs $Q_1$ and $Q_2$ are turned on, the input voltage $V_{in}$ is applied, the inductor L stores the energy, output capacitor supplies the load current entirely.

When $Q_1$ and $Q_2$ are turned off, MOSFETs $Q_3$, $Q_4$ are turned on in this stage the energy is transferred from the inductor to output load and capacitor. Here we are using a synchronous rectification scheme these means we are using MOSFETs instead of diodes to reduce the switching and power losses and to improve efficiency. The Figure shows the equivalent circuit of the converter in buck and boost mode. When Vin is higher than Vout, The MOSFET $Q_2$ is always OFF, $Q_4$ is always ON, $Q_1$ and $Q_3$ ON and OFF simultaneously thus it works like a buck converter ($V_{in} > V_{out}$) as shown in below figure. When Vin is lower than $V_{out}$, $Q_1$ is always ON and $Q_3$ is always OFF, $Q_2$ and $Q_4$ ON and OFF simultaneously it works as a boost converter ($V_{in} < V_{out}$) as shown in below figure.

## Current regulated PWM inverters

Current regulation technique plays the most important role in Current Regulated PWM (CR-PWM) inverters which are widely applied in ac motor drives, ac power supply and active filters. The CR-PWM inverters, also known as current mode PWM inverters, implement an on line current feedback (closed loop) type of PWM. In comparison to a conventional feed forward (open loop) voltage controlled PWM inverters they show following advantages: - control of instantaneous peak current, - overload problem is avoided, - pulse drop problem does not occur, - extremely good dynamics, - nearly sinusoidal current waveforms, expect for the harmonics - compensation of the effect of load parameter changes (resistance and reactance). The basic problem involved in the implementation of CR-PWM inverters is the choice of suitable current regulation strategy, which affects both the parameters obtained. The main task of the control system in CR-PWM inverter is to force the current vector in the three phase load according to the reference trajectory.