LINE COMMUTATED CONVERTERS

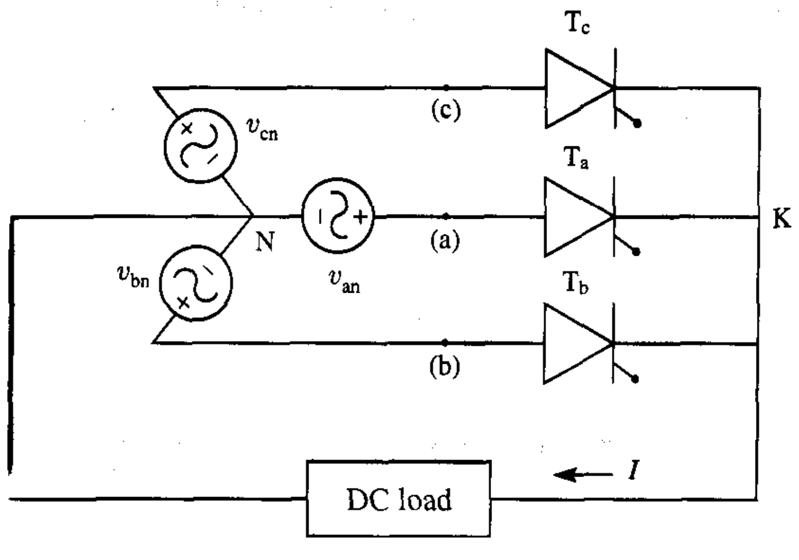
INTRODUCTION

A static power converter makes use of a configuration of power semiconductor devices that function as switches. These are made to turn ON and turn OFF repetitively in such a way as to implement the required conversion function. Whenever a switch is turned OFF, the path of the current flow changes, that is, there is a "commutation" of current away from that switch.

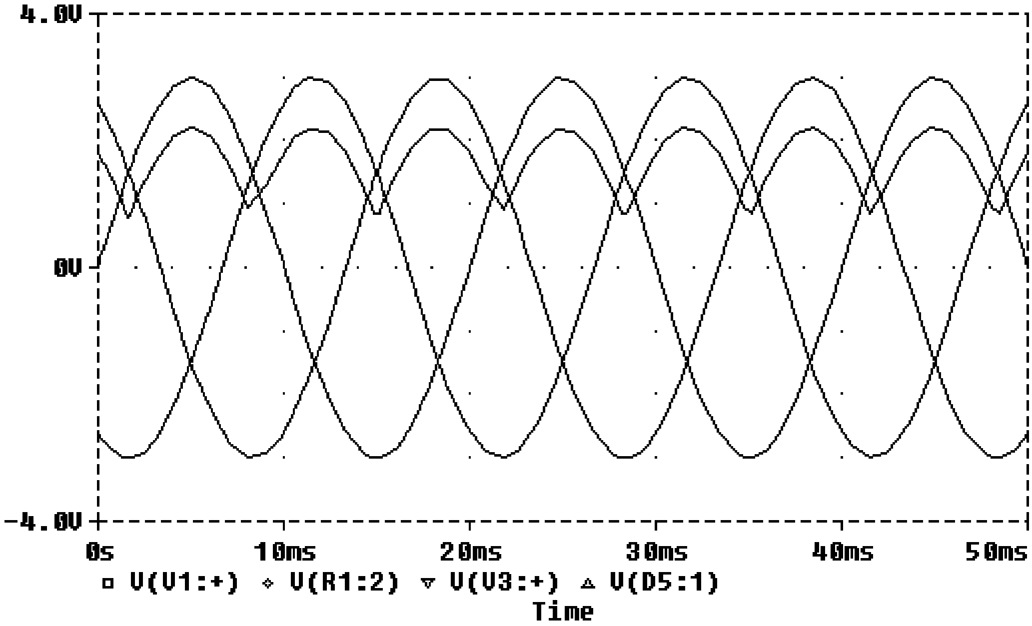
A conducting diode is automatically commutated, that is, turned OFF, when a reverse bias voltage appears across it. A conducting thyristor is also commutated in a similar manner because the gate is ineffective to achieve commutation. The reverse voltage that serves to turn OFF a thyristor or diode is called the commutating voltage. We can turn OFF a thyristor by injecting a reverse bias across it and "force" it to turn OFF.

For example, if the converter is a rectifier, an AC supply is already available at the input terminals for conversion to DC. We can commutate a conducting thyristor by using this voltage, during intervals of time when it has the proper polarity.

We shall illustrate this description of line commutation by reference to Fig. 1. This circuit is basically a three-phase rectifier circuit that converts a three-phase AC input into DC. In this figure, *v^n,* fbn and fen are three identical AC voltages that differ in phase mutually by 120° and therefore constitute a balanced three-phase supply.



The switching elements are the three thyristors labeled Ta, Tb and TC;. The gate circuits of these thyristors are not shown in the figure for the sake of clarity. The "line voltage" *Vba* = *Vbn* - *Van* is an alternating voltage. Let us assume that thyristor *Ta* has been turned ON during an interval in the AC cycle when it is forward-biased and that it is conducting current into the load from e (a) phase source. Let us assume that the other two thyristors are OFF.



By sequentially firing an incoming thyristor when the line voltage has the correct polarity, we can successively commutate each thyristor. Such a scheme does not require any special force commutation circuit to "artificially" generate and apply a reverse as pulse to commutate an outgoing thyristor. The incoming thyristor automatically applies the line voltage in reverse to the outgoing thyristor, which is commutated "naturally." The term "natural commutation" has also been used to describe this type of commutation. We shall, however, use term "line commutation."

Therefore we see two aspects of line commutation. First, line commutation is possible only in converters that are connected to an AC voltage bus, because the presence of an alternating voltage is necessary to serve as the commutating voltage. Second, to successfully achieve turn OFF switching by means of line commutation, it is essential that the associated line voltage, which serves as the commutating voltage, must have the polarity that will verse-bias the outgoing thyristor.

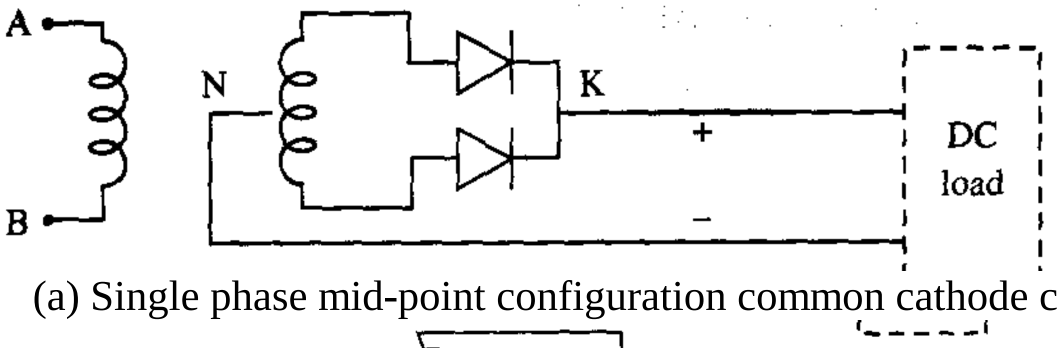
Diode Rectifiers—Basic Configurations of the Switching Elements

There are two basic rectifier configurations which are most commonly used for large power applications. These are

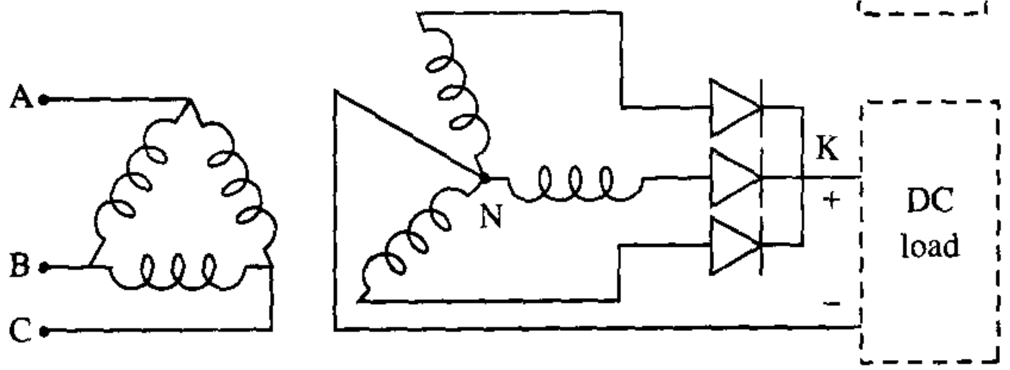
1. the midpoint configuration and
2. the bridge configuration.

1 MIDPOINT CONFIGURATION.

Figure 3 shows single-phase (a) and three-phase midpoint rectifier circuit configurations (b). The midpoint configuration requires a transformer, which has to have a "midpoint," and this midpoint is one terminal of the DC output as shown in the Fig.3..



(a) Single phase mid-point configuration common cathode circuit



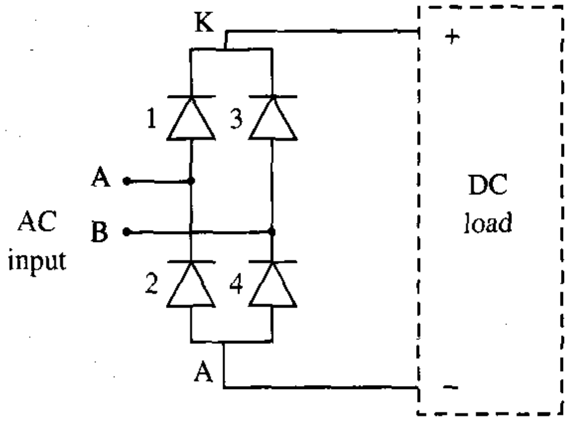
(b) Three phase mid-point configuration common cathode circuit

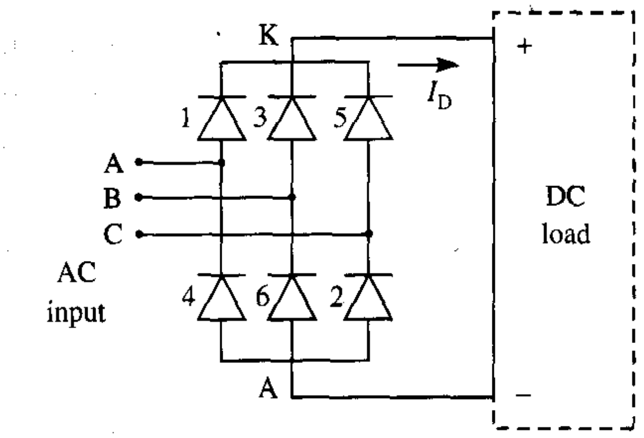
This secondary neutral terminal, labeled N in (a) and (b*)*, serves as the midpoint. The transformer has to handle the full power of the converter. Because of this, the midpoint configuration makes the converter larger and heavier.

But the transformer provides two benefits. First, it provides electrical isolation between the input AC side and the output DC side. Second, the voltage ratio of the transformer can be suitably chosen to match the required DC side voltage, to the available AC bus voltage.

2 **THE BRIDGE CONFIGURATION.**

Figure 4 shows the bridge configuration for single-phase and three-phase AC inputs. The bridge requires double the number of switching elements compared with the midpoint configuration. The bridge basically consists of a common cathode circuit and a common anode circuit. Half the total number of switching elements have their cathodes connected together at the common cathode terminal labeled K. The remaining half of the switching elements have their anodes connected together at the common anode terminal labeled A. This is the negative current terminal.





In the bridge configuration, the DC current has to flow simultaneously through two switching elements—one belonging to the common cathode section and the other belonging to the common anode section. This is a disadvantage in comparison with the midpoint circuit. But the main advantage of the bridge circuit over the midpoint circuit is that there is no necessity to use a transformer, which means a large reduction in cost, weight and size. But a transformer may still be necessary if electrical isolation between the AC and DC sides is a requirement. It may also have to be used for stepping up or stepping down the AC voltage, as a means of overcoming a disparity in the available AC bus voltage and the required DC voltage.

UNCONTROLLED, CONTROLLED AND SEMICONTROLLED RECTIFIERS

1 UNCONTROLLED RECTIFIERS.

When all the switching elements of a rectifier are diodes, we call it an uncontrolled rectifier. We do not have a means of controlling the switching instants of the devices. Each diode automatically turns ON at the instant when it becomes forward-biased and turns OFF when it becomes reverse-biased. Uncontrolled rectifiers have a fixed voltage ratio between the DC output voltage and the r.m.s. AC input voltage. Since all the switching elements of an uncontrolled rectifier are diodes, there is no need for a control circuit block for this category of rectifiers.

2 CONTROLLED RECTIFIERS.

When all the switching elements of a rectifier are thyristors, we call it a controlled rectifier. We can change any of the rectifier circuits in Figs. 3 and 4 from the uncontrolled category to the controlled category by replacing every diode by a thyristor.

In contrast to a diode, a thyristor does not automatically turn ON at the instant in the AC cycle at which it becomes forward-biased. After it has become forward-biased, it waits till a gate pulse is impressed on its gate terminal. The controlled rectifier has a control circuit block to generate and supply the "gate trigger pulse," also called the "gate firing pulse," to each thyristor at the appropriate instant in every switching cycle. Control of the DC output is achieved by adjusting the delay time of the gate firing pulse to each thyristor from the instant it would have turned ON had it been a diode. In other words, we are adjusting the "phase" of the gate firing pulse with respect to a reference instant, which for each thyristor is the instant at which it starts to get forward-biased. For this reason, this type of control is generally described as "phase control." In a controlled rectifier, since all the switching elements are thyristors, phase control can be exercised over every switching element.

3 SEMICONTROLLED RECTIFIERS**.** In addition to uncontrolled and controlled rectifiers, there is a third category, known as "semicontrolled" or "half-controlled" rectifiers. In a semicontrolled rectifier, some of the switching elements will be thyristors and the rest diodes. A typical semicontrolled rectifier uses the bridge configuration.. Such an arrangement is shown in Figs. 5(a) and (b).

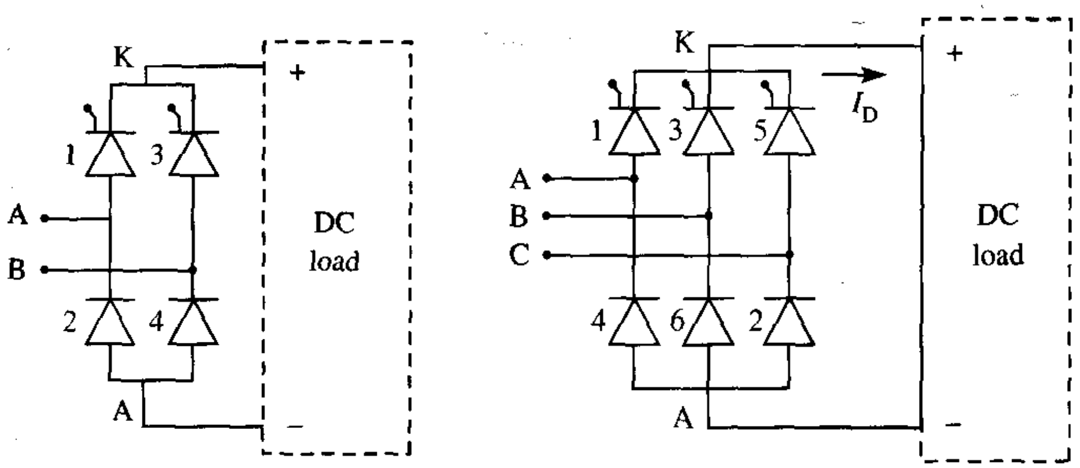


Figure 5. (a) (b)

The semicontrolled bridge is used primarily for reasons of economy, in situations that do not demand a fully controlled bridge. There will be a saving in cost, because diodes are less costly than thyristors.

"FIRING ANGLED—THE MEANS OF PHASE CONTROL

We have stated in the previous section that phase control is exercised by delaying the ON switching of a thyristor by an adjustable delay time, after it has become forward-biased, that is, after the instant it would have turned ON had it been a diode. This time delay is usually expressed in angular measure, by treating one full period of the AC input as equal to 360°. This phase angle delay is commonly known as the "firing angle" of the switching element. For a diode the firing angle α is always zero, whereas for a thyristor α is adjustable by phase control.

The voltage conversion ratio, between the DC output and the AC input is a function of the firing delay angle α. For the uncontrolled rectifier, this ratio will be constant because α has a fixed zero value.

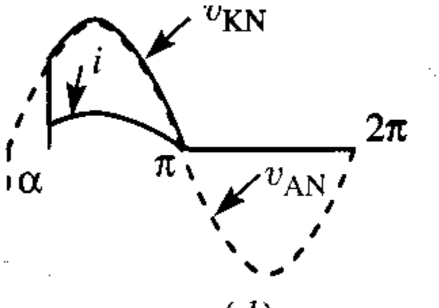
THE SINGLE-PHASE HALF-WAVE RECTIFIER

The single-phase half-wave rectifier uses only one switching element, which may be a diode or a thyristor. It is seldom used for high power applications. The more popular configurations for power rectification are the midpoint circuit and the bridge circuit.

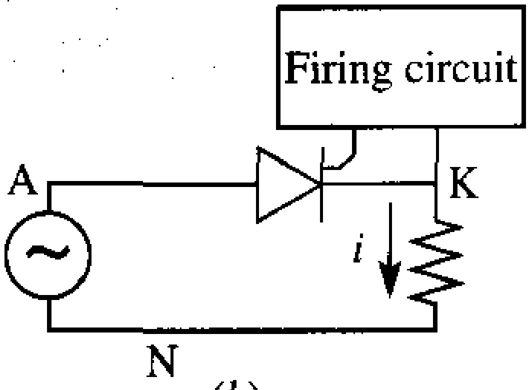
The Single-Phase Half-Wave Rectifier with Resistive Load

Figure 6 (a) shows the circuit with a diode or thyristor as the switching element. This AC input voltage is assumed to be sinusoidal, and its waveform is shown by the broken lines in Figs. 6*(b)*. The DC output terminals are labelled K and N.

In the diode circuit, the diode will turn ON at the instant when it becomes forward-biased, that is, the instant labeled 0 in Fig. 6(c). It will commutate (turn OFF) at the instant at which it starts to get reverse-biased, that is, the instant labeled π in Fig. 6. From π, it will be in the OFF state and remain reverse-biased till 2 π. The cycle of switching will then again repeat.



(*d*)



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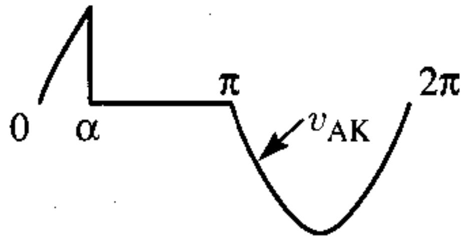
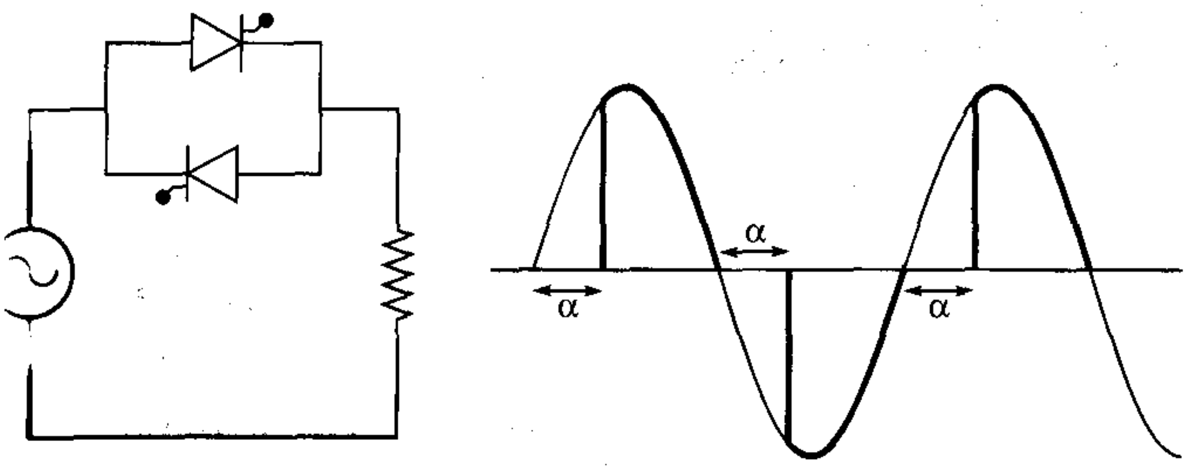


(*f*)

PHASE CONTROL—RESISTANCE LOAD

Figure 7 illustrates phase control of a resistance load supplied from a single-phase **AC** source. Here the AC switch is gated in every half-cycle. The instant at which it is turned ON is delayed by an angle labeled as α in the figure.



The power control is achieved by variation of this firing angle α. Since the power in the load is proportional to the square of the r.m.s. value of the voltage, we shall obtain a relationship between the firing angle α and the r.m.s. load voltage as follows. For this, we first determine the mean square value:

$$V_{mean}^2 = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\theta d\theta = \frac{V_m^2}{2\pi}\int_{\alpha}^{\pi}\left(1-2\cos^2\theta\right)d\theta =$$

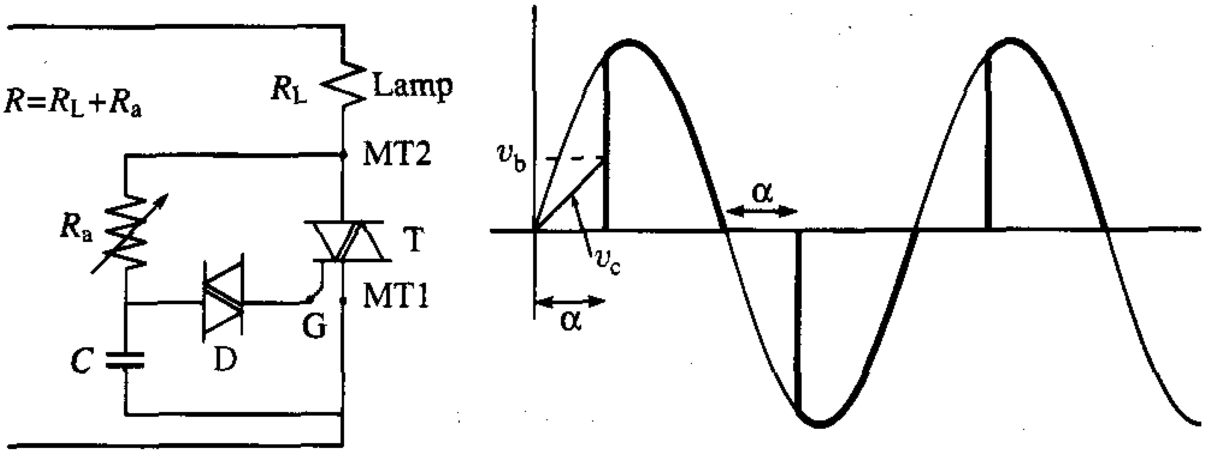
$$= \frac{V_m^2}{2\pi}\left(\pi-\alpha+\frac{1}{2}\sin 2\alpha\right)$$

$$V_{rms} = V\sqrt{1-\frac{\alpha}{\pi}+\frac{\sin 2\alpha}{2\pi}}$$

With phase control, the AC load current can be seen to be non-sinusoidal. Therefore this technique creates what may be called "subharmonic" frequency currents in the system.

THE TRIAC LIGHT DIMMING CIRCUIT

This circuit is very widely used for the dimming control of incandescent filament lamps. It is essentially a pracitcal example of the phase control of a single phase resistance load which was described above. The AC switch used is a triac. Another bidirectional switching device, which goes by the name "diac" is commonly used in the triggering circuit of triacs in light dimming controllers. The diac is a two terminal device that turns ON when the voltage across it exceeds its breakover voltage limit.



The circuit arrangement is shown in Fig. 8. In each half-cycle of the AC, the capacitor *C* gets charged through the charging resistor *R*, The charging rate will be determined by the time constant *CR*, and will be slower the higher the value of *R*. When the capacitor voltage crosses the breakover voltage of the diac, the diac switches ON and causes the capacitor to discharge into the gate of the triac and so turn it ON. The firing angle at which the diac turns on is adjustable by varying the value of the charging resistor *R*, which is the intensity control for the lamp.

The firing of the triac occurs at the instant when the capacitor voltage (v_c) rises to the breakover voltage of the diac (v_b).

This is described by the following relation:

$$\frac{v_b}{V_m} = \frac{\sin(\alpha - \varphi) + \exp(-\alpha / \omega CR)\sin\varphi}{\sqrt{1 + \omega^2 C^2 R^2}}$$

where $\varphi = \tan^{-1}(\omega CR)$

DC/AC VOLTAGE RELATIONSHIP

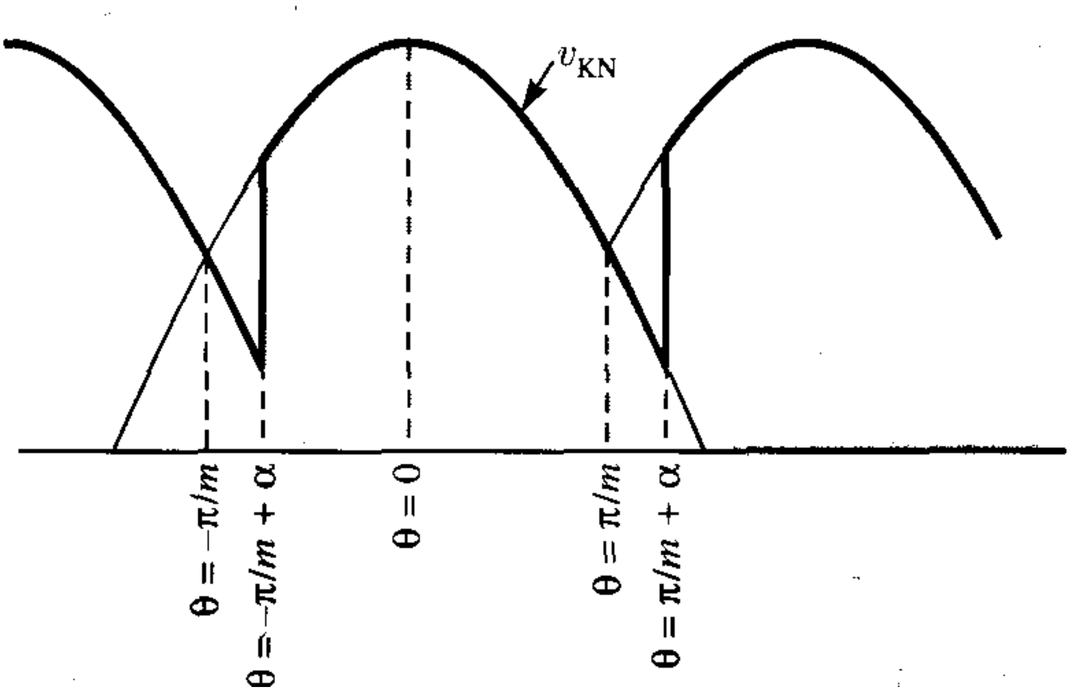
In the general case of an m -phase or m -pulse rectifier, the DC component of the output voltage can be determined by taking the average over one repetitive period of the waveform of the output terminal voltage VKN- We shall make the following ideal assumptions.

1. The phase voltage waveforms are ideal sine waves.
2. The switching elements are ideal, with zero ON state voltage drop and zero OFF state leakage.
3. Commutation is instantaneous.
4. There is infinite inductive smoothing on the DC side.
5. There is continuous conduction over the entire interval of $2\pi/m$ for each phase, whether or not there is excursion into the negative region of the phase voltage.

The waveform of the voltage VKN at the output terminals of the midpoint rectifier in Fig. 9. In this figure, the reference zero used for the phase angles is the instant of positive peak of the phase voltage waveform. The instant of positive peak express the phase voltage as

$$v = V_m \cos\theta$$

Then.



$$V_{DC} = \frac{1}{2\pi/m}\int_{-\pi/m+\alpha}^{\pi/m+\alpha} V_m \cos\theta d\theta = \frac{V_m \sin(\pi/m)}{\pi/m}\cos\alpha = \left(\frac{\sqrt{2}m}{\pi} V_p \sin(\frac{\pi}{m})\right)\cos\alpha$$