AC -to- DC Converters

(Uncontrolled Rectifiers)

This document content the uncontrolled rectifiers or Diode Rectifiers.
The document is prepared from the concepts given in references

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(Uncontrolled Rectifiers)

Rectification is the process of conversion of alternating input voltage to direct output voltage. Rectifier converts ac power to dc power. Rectifiers are of two types uncontrolled rectifiers and controlled rectifiers. The rectifier which uses uncontrolled power electronics devices as their power converting device are known as uncontrolled rectifier, whereas those use controlled devices for power conversion are known as controlled rectifiers. Diode based rectifiers are uncontrolled rectifiers whereas thyristor based are known as controlled rectifiers.

A rectifier may be half-wave type or full- wave type. A half-wave rectifier is one in which current in any one line, connected to ac source, is unidirectional. However, a full-wave rectifier has bidirectional current in any one line connected to ac source.

A rectifier may be one-pulse, two-pulse, or *n*-pulse type where,

Pulse number = number of load current (or voltage) pulses during one cycle of ac source voltage.

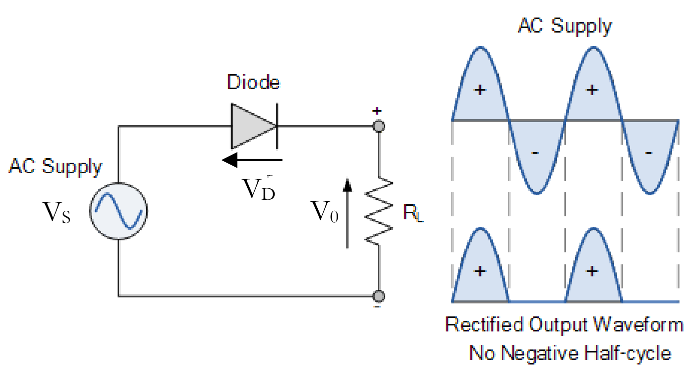
Single-phase Half Wave Rectifier

Single phase uncontrolled half-wave rectifiers are the simplest and possibly the most widely used rectification circuit for small power levels as their output is heavily affected by the reactance of the connected load.

For uncontrolled rectifier circuits, semiconductor diodes are the most commonly used device and are so arranged to create either a *half-wave* or a *full-wave* rectifier circuit. The advantage of using diodes as the rectification device is that by design they are unidirectional devices having an inbuilt one-way pn-junction.

This pn-junction converts the bi-directional alternating supply into a one-way unidirectional current by eliminating one-half of the supply.

Half-wave Rectification (R Load)



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, it 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.

Thus, there is no voltage or current applied to the connected load, R_L for half of each cycle. In other words, the voltage across the load resistance, R_L 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*.

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 ($\sin(90^o)$), 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.

Sinusoids Average Value

Input voltage is$V_s = V_m \sin \omega t$

Average value of output for load voltage, □□

$$V_0 = \frac{1}{2\pi}\int_0^{\pi} V_s \, d(\omega t)$$

$$V_0 = \frac{1}{2\pi}\int_0^{\pi} V_m \sin \omega t \, d(\omega t)$$

$$= \frac{V_m}{2\pi} |-\cos \omega t|_0^{\pi}$$

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

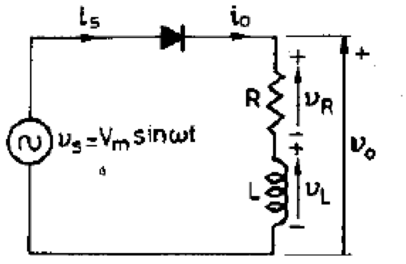
RMS value of output voltage,

$$V_{0r} = \left[\frac{1}{2\pi}\int_0^{\pi} V_m^2 \, sin^2(\omega t) \, d(\omega t)\right]^{1/2}$$

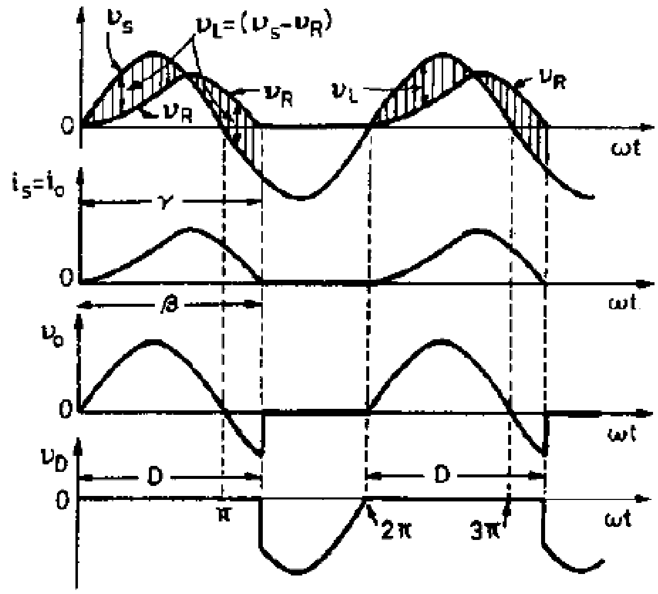
$$= \frac{V_m}{\sqrt{2\pi}}\left[\int_0^{\pi} \frac{1-\cos 2\omega t}{2} d(\omega t)\right]^{1/2}$$

$$= \frac{V_m}{2}$$

RL Load :



(a)



(b)

A single-phase one-pulse diode rectifier feeding RL load is shown in Fig a. Current i_0 continues to flow-even after source voltage v_s has become negative; this is because of the presence of inductance L in the load circuit. After positive half cycle of source voltage, diode remains on, so the negative half cycle of source voltage appears across load until load current i_0 decays to zero at ωt=β. Voltage $v_R=i_0R$ has the same wave shape as that of i_0.

When $i_{0=0}$ at ωt=β; v_L =0, v_R=0 and voltage v_s appears as reverse bias across diode D as shown. At β, voltage v_D across diode jumps from zero to V_m sin β where β > π. Here β = γ is also the conduction angle of the diode.

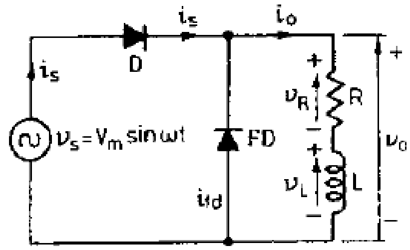
Average value of output voltage,

$$V_0 = \frac{1}{2\pi}\int_0^{\beta} V_m sin\ \omega t.d(\omega \text{t}) = \frac{V_m}{2\pi}(1-\cos\beta)$$

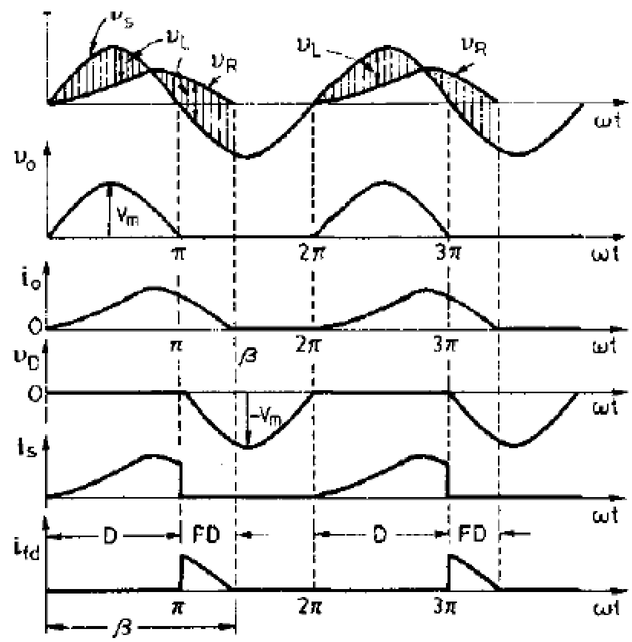
Average load or output current

$$I_0 = \frac{V_0}{R} = \frac{V_m}{2\pi R}(1-\cos\beta)$$

RL Load with Freewheeling Diode:



(a)



To improve the performance of single- phase one-pulse diode rectifier freewheeling diode (*FD*) is connected across the *RL* load as shown in above fig a. The output voltage is $v_0 = v_S$ for $0 \le \omega t \le \pi$. At ωt=π, source voltage v_S is zero, while the output current i_0 is not zero because of *L* in the load circuit. Just after ωt=π, as v_S tends to reverse, negative polarity of v_S reaches cathode of *FD* through conducting diode *D*, whereas positive polarity of v_S reaches anode of *FD* direct. *FD* is thus forward biased. Hence the load current i_0 is immediately transferred from *D* to *FD* as v_S tends to reverse. After ωt=π, diode or source current i_S=0 and diode *D* is subjected to reverse voltage with PIV equal to V_m at ωt=3π/2, 7π/2 etc.

After ωt=π, current freewheel through circuit *R*, *L*, and *FD*. The energy stored in *L* is dissipated in *R*. When energy stored in *L* = energy dissipated in *R*, current falls to zero at ωt=β<2π. Depending upon the value of *R* and *L*, the current may not fall to zero even when ωt=2π, then it became continuous conduction. In the above fig. b the load current decays to zero before 2π.Here this is discontinuous conduction is shown.

The average output voltage is $V_0 = \frac{1}{2\pi}\int_0^{\pi} V_m sin\ \omega t.d(\omega t) = \frac{V_m}{\pi}$

The value of average load current, $I_0 = \frac{V_m}{\pi R}$

The functions of freewheeling diode in the circuit as under:

(i) It prevents the output voltage from becoming negative.
(ii) As the stored energy of *L* is transferred to load *R* thus the system efficiency is improved.
(iii) Nature of load current become more smoother and better.

Single-phase Full -wave Diode Rectifier

Centre tapped and full wave bridge rectifiers are the two types of full-wave diode rectifiers.

(i) Single-Phase Full-Wave Mid-Point or Centre-Tapped Diode Rectifier:

The circuit diagram of a single-phase full-wave mid-point or center-tapped diode rectifier is shown in Fig. a. When the terminal '*a*' is positive with respect to '*b*', or mid-point *O*, Diode D1 conducts for π period. In the next half cycle, '*b*' is positive with respect to '*a*', or mid-point *O*, then diode D2 conducts. v_0 is the output voltage which is shown in Fig. b. At the time when '*a*' became positive with respect to '*b*' , the voltage across diode D2 is reverse biased and it became $2v_s$. In the next half cycle, diode D1 experiences a reverse voltage of $2v_s$. Thus, for diodes D1 and D2, peak inverse voltage is $2V_m$. Waveforms of Fig. (b) show that for one cycle of source voltage, there are two pulses of output voltage. So single-phase full-wave diode rectifier can also be called single-phase two-pulse diode rectifier.

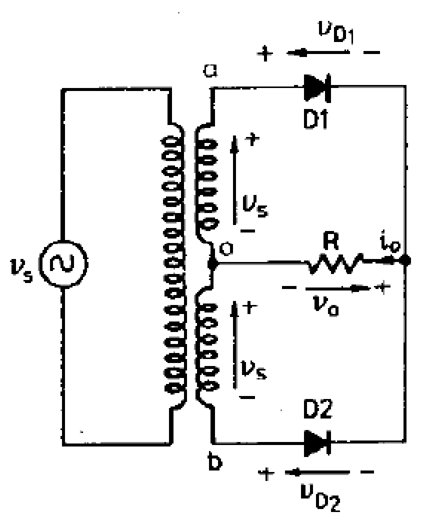


Fig. a

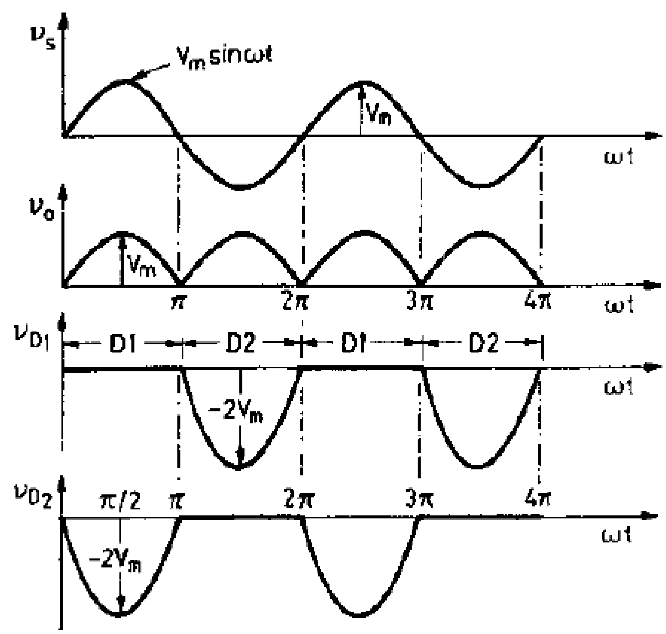


Fig. b

Average value of output voltage,

$$V_0 = \frac{1}{\pi}\int_0^{\pi} V_m sin\ \omega t. d(\omega t) = \frac{2V_m}{\pi}$$

Average load or output current,

$$I_0 = \frac{V_0}{R} = \frac{2V_m}{\pi R}$$

Rms voltage ,

$$V_{0r} = \frac{1}{\pi}\int_0^{\pi} [V_m^2 sin^2 \omega t. d(\omega t)]^{1/2} = \frac{V_m}{\sqrt{2}} = V_s$$

Rms current,

$$I_{0r} = \frac{V_s}{R}$$

Load power,

$$= V_{0r}.I_{0r} = {I_{0r}}^2.R$$

(ii) Single-Phase Full-Wave Diode Bridge Rectifier:

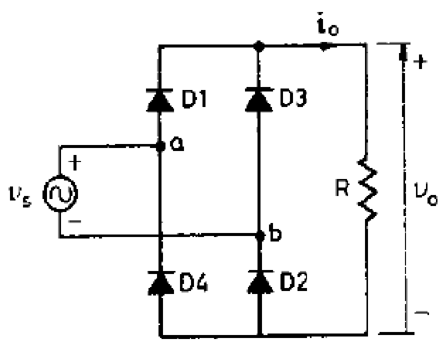


Fig. a

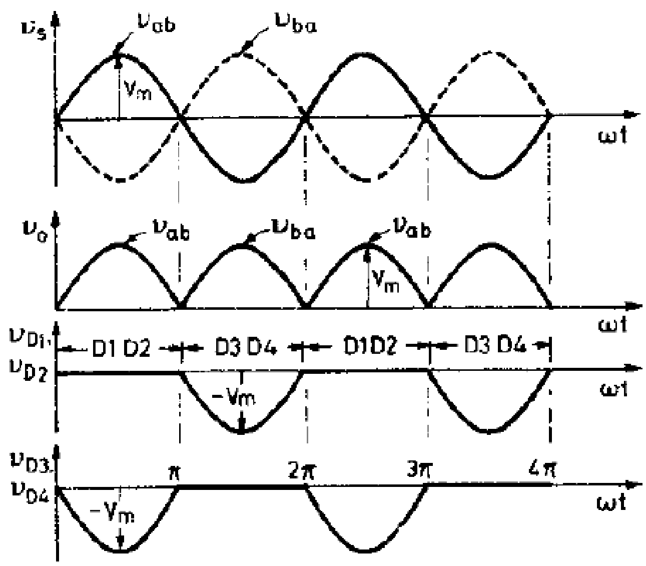


Fig. b

A single-phase full-wave bridge rectifier employing diodes is shown in above Fig. (a). When 'a' is positive with respect to 'b', diodes Dl, D2 conduct together so that output voltage is v_{ab}. Each of the diodes D3 and D4 is subjected to a reverse voltage of v_s as shown inFig. (b), When 'b' is positive with respect to 'a', diodes D3, D4 conduct together and output voltage is v_{ba}· Each of the two diodes Dl and D2 experience a reverse voltage of v_s as shown.

In comparison in case of a mid-point full-wave rectifier diodes are subjected to PIV of 2V_m whereas a diode in full-wave bridge rectifier has PIV of V_m only.

Three-phase Diode Rectifiers

To supply high power and voltage three phase rectifiers are preferred compared to single phase rectifiers.

The various types of three phase diode rectifiers are-

(i) Three phase half wave rectifier
(ii) Three phase mod point 6-pulse rectifier
(iii) Three phase bridge rectifier
(iv) Three phase 12 pulse rectifier

(i) Three Phase Half-Wave Diode Rectifier

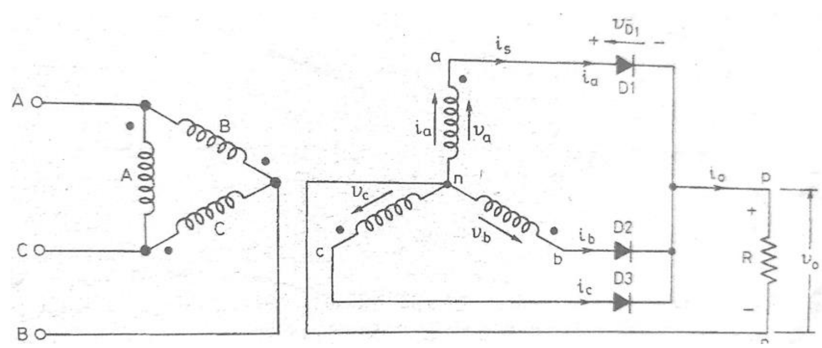
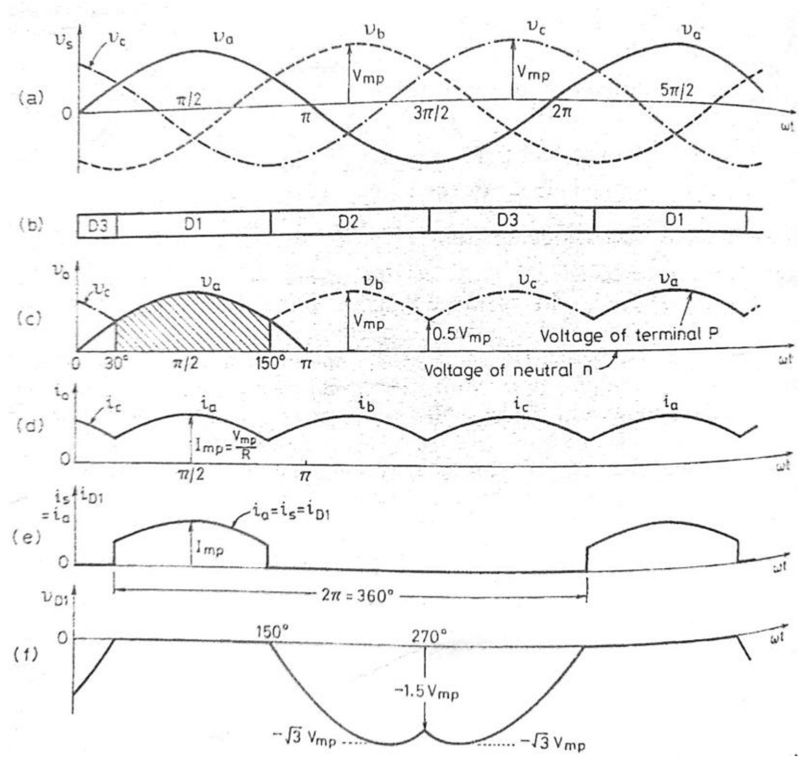


Fig. a

The three phase half-wave rectifier circuit is shown above Fig. a. Due to connections of all the cathode of diodes together this is known as common cathode circuit.

The rectifier element connected to the line at the highest positive instantaneous voltage can only conduct. The voltage and current waveforms are shown below in figure. A diode with the highest positive voltage will begin to conduct at the cross-over points of the three-phase supply. It is seen from this figure that the diode D1 will conduct for ωt= 30° to ωt= 150° as this diode senses the most positive voltage v_a, as compared to the other two diodes, during the interval. Diode D2 will conduct from ωt= 150° to ωt= 270° and Diode D3 from ωt= 270° to ωt= 390°. When a diode is conducting, the common cathode terminal *P* rises to the highest positive voltage of that phase and the other two blocking diodes are reversed biased. The conduction of diodes in proper sequence is shown in Fig. b. The voltage v_0 across the load follows the positive supply voltage envelope and has the waveform as shown in Fig. c. The dc load voltage v_0 varies between V_{mp} (=maximum phase voltage) and $0.5V_{mp}$. It is observed that for one cycle of supply voltage, output voltage has three pulses. This circuit can therefore be called a 3-phase 3-pulse diode rectifier or three phase half-wave diode rectifier.



(ii) Three Phase Mid -Point 6-pulse Diode Rectifier

This rectifier is also called six-pulse half-wave diode rectifier or three-phase M-6 diode rectifier. Figure (i) below shows a three-phase mid-point6-pulse rectifier using six diodes.

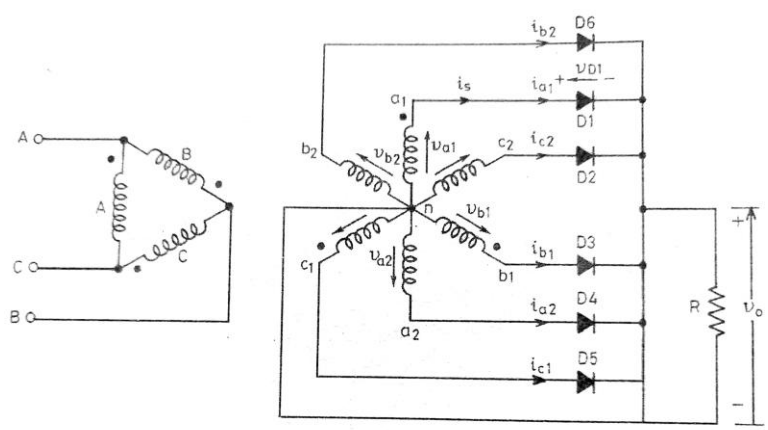
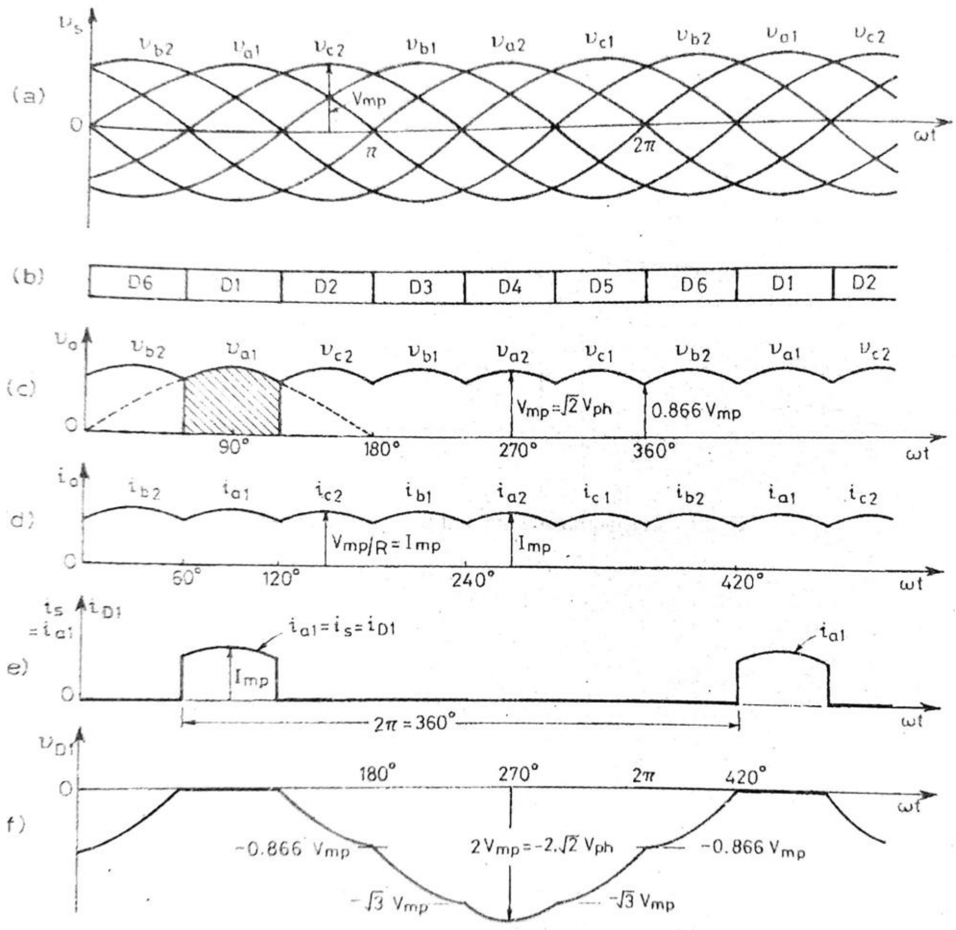


Fig. (i)

A three phase transformer with primary in delta and secondary in double star is used. One diode in each phase is connected as shown. The secondary of each phase winding is connected is in two halves. The mid points of the three phase secondary windings are connected to form the neutral n. Six-phase supply is available from six terminals a_1, c_2, b_1, a_2, c_1, and b_2.

The waveform of six-phase voltages v_{a1}, v_{c2}, v_{b1} are sketched in Fig.a. Diodes having highest positive anode potential gets forward biased and conducts. Therefore, from ωt= 0° to ωt= 60°, voltage v_{b2} is the highest positive, therefore diode D6 conducts, similarly for other diodes.



□ The average output voltage is,

$$V_0 = \frac{1}{\pi/3}\int_{\pi/3}^{2\pi/3} V_{mp} sin\ \omega t . d(\omega \text{t}) = \frac{3V_{mp}}{\pi}$$

Rms voltage of the output voltage,

$$V_{0r} = \left[\frac{1}{\pi/3}\int_{\pi/3}^{2\pi/3} \left(V_{mp} sin\ \omega t\right)^2 . d(\omega \text{t})\right]^{1/2} = 0.9558V_{mp}$$

Ripple voltage, $V_r = \sqrt{{V_{0r}}^2 - {V_0}^2}$=0.043 or 4.3%

(iii) Three Phase Diode Bridge Rectifier

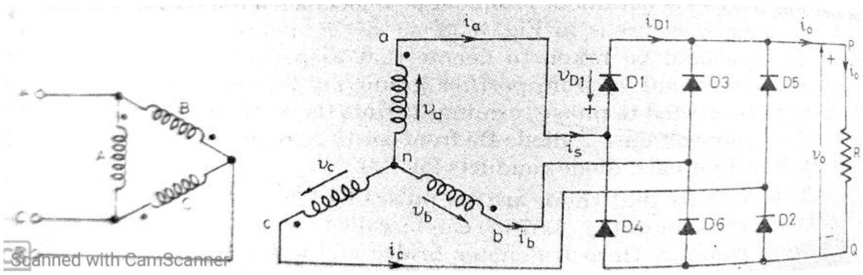


Fig. (i)

Power circuit diagram for a three-phase bridge rectifier using six diodes is shown in above Fig.(i). The diodes are arranged in three legs. Each leg has two series-connected diodes. Upper diodes D1, D3, D5 constitute the positive group diodes. The lower diodes D2, D4, D6 form the negative group of diodes. The three-phase transformer feeding the bridge is connected in delta-star. This rectifier is called 3-phase 6-pulse diode rectifier, 3-phase full-wave diode rectifier, or three phase B-6 diode rectifier.

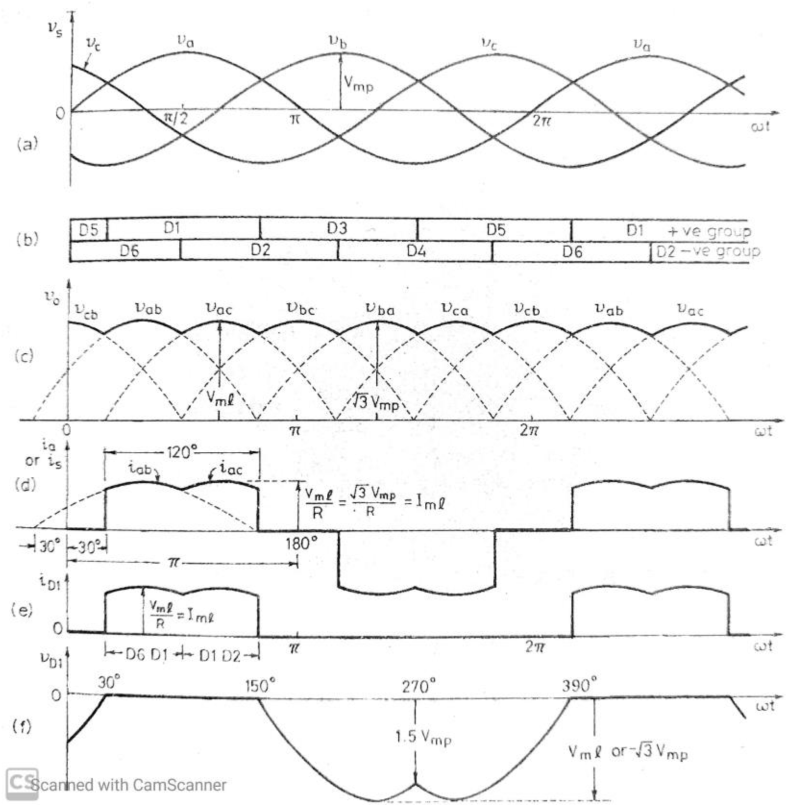


Fig.(ii)

In this circuit positive group of diodes conduct when these have the most positive anode. Similarly, negative group of diodes would conduct if these have the most negative anode. It is seen from the source voltage waveform v_s of Fig. ii(a) that from ωt= 30° to ωt= 150°, v_a is more positive than v_b or v_c. Therefore, diode D1 connected to line 'a' conducts during the interval ωt= 30° to ωt= 150°. Likewise, from ωt= 150° to ωt= 270°, v_b is more positive than v_a or v_c ; therefore, diode D3 connected to line 'b' conducts during the interval ωt= 150° to ωt= 270°. Similarly, diode D5 from the positive group conducts from ωt= 270° to ωt= 390° and so on.

Voltage v_c is the most negative from ωt= 90° to ωt= 210°. Therefore, negative group diode D2 connected to line 'c' conducts during this interval. Similarly, diode D4 conducts from ωt= 210° to ωt= 330° and diode D6 from ωt= 330° to ωt= 450° and so on.

Average value of load voltage,

$$V_0 = \frac{1}{periodicity}\int_{a1}^{a2} v_{ab} d(\omega t)$$

$$V_0 = \frac{1}{\pi/3}\int_{\pi/6}^{\pi/2} V_{ml} sin\,(\omega t + 30°).\,d(\omega \text{t}) = \frac{3.\sqrt{2}V_l}{\pi} = \frac{3.\sqrt{6}V_p}{\pi}$$

$$V_{ml} = maximum\ value\ of\ line\ voltage$$

$$V_l = rms\ value\ of\ line\ voltage\ and$$

$$V_p = rms\ value\ of\ phase\ voltage$$

Rms voltage of the output voltage,

$$V_{0r} = \left[\frac{1}{\pi/3}\int_{\pi/3}^{2\pi/3} (V_{ml} sin\ \omega t)^2.\,d(\omega \text{t})\right]^{1/2} = 0.9558 V_{ml}$$

Ripple voltage, $V_r = \sqrt{{V_{0r}}^2 - {V_0}^2}$=0.0408 V_{ml}

(iv) Three Phase Twelve-pulse Rectifier

When the number of pulses per cycle increased, the output dc waveform gets improved. So, with twelve pulses per cycle, the quality of the output voltage waveform would definitely be improved with low ripple content.

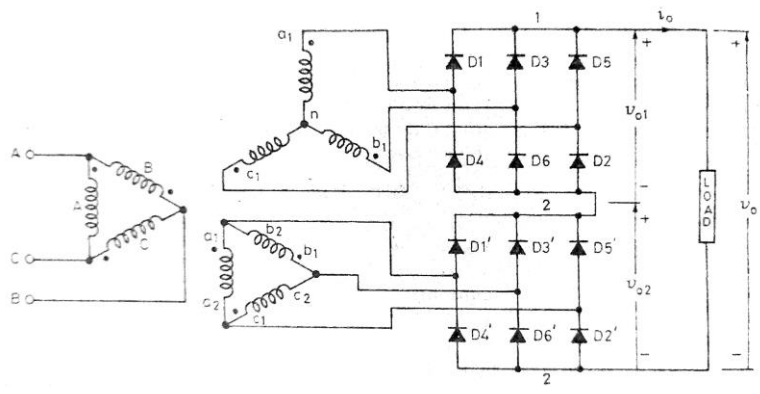


Fig. (i)

Fig. (i) shows the twelve-pulse rectifier using a total twelve diodes.

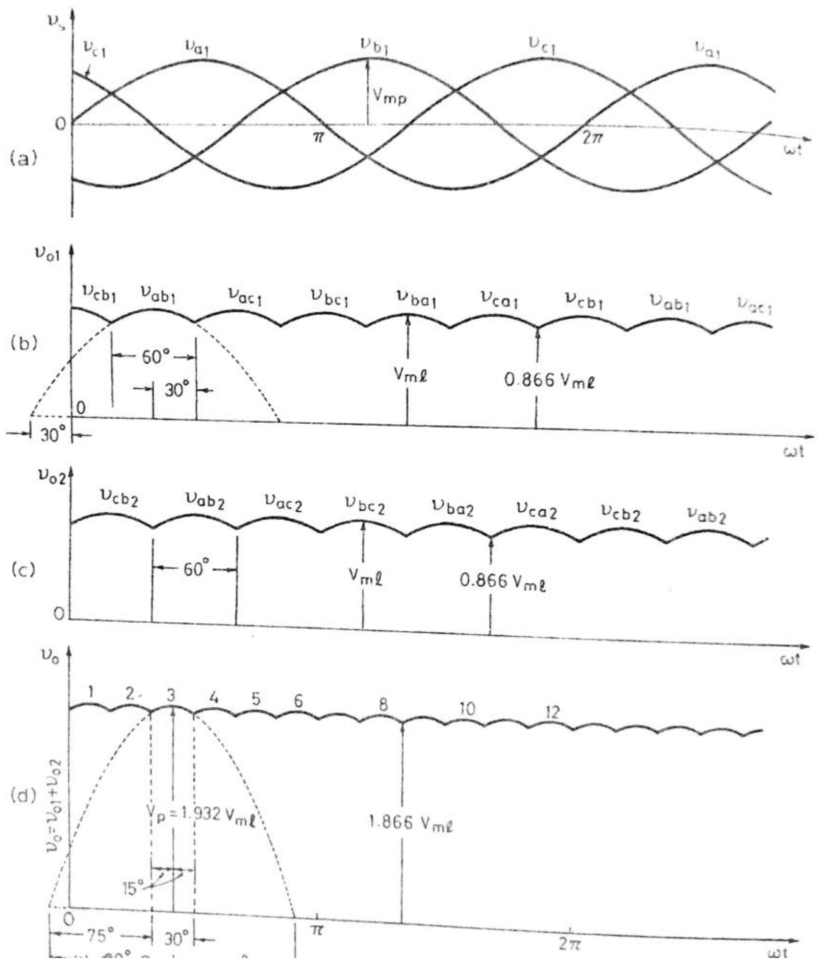


Fig. (ii)

The waveforms of the rectifier input and output waveforms are shown in fig(ii) above.

Average value of load voltage,

$$V_0 = \frac{1}{\pi/6}\int_{75^\circ}^{105^\circ} V_p sin\ \omega t. d(\omega \mathrm{t}) = 0.988616V_p$$

Rms voltage of the output voltage,

$$V_{0r} = \left[\frac{1}{\pi/6}\int_{75^\circ}^{105^\circ} {V_p}^2 \ \ sin^2\ \omega t. d(\omega t)\right]^{1/2} = 0.988668V_p$$

Ripple voltage, $V_r = \sqrt{{V_{0r}}^2 - {V_0}^2}$=0.019545 V_{ml}

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