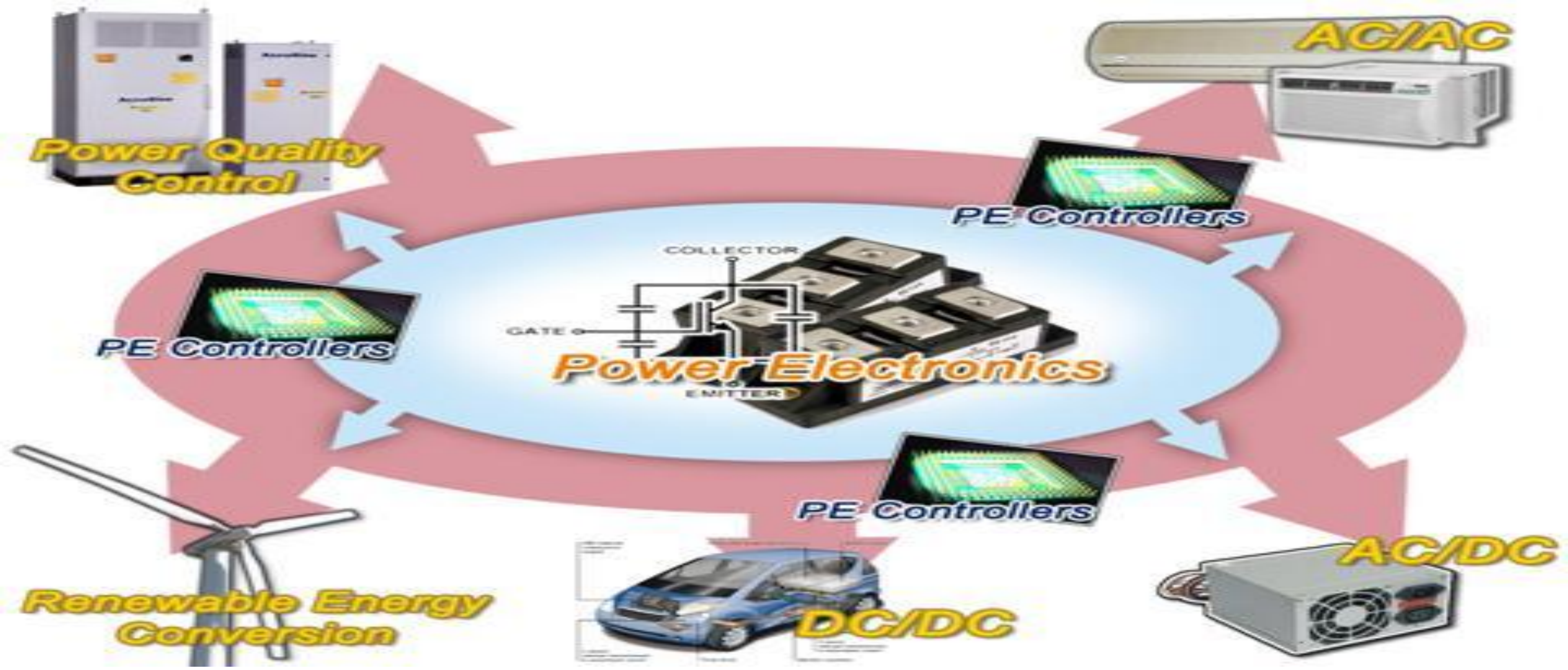


Chapter 2 AC - DC Converter

Contents of Chapter

- Single phase and three phase rectifier (type of AC input)
- Uncontrolled and controlled rectifier (use of diode or SCR)
- Analysis with R, R-L and R-L-E laod
- Effect of source impedance
- PF improvement for uncontrolled rectifier
- Filters

Diode Circuits or Uncontrolled Rectifier

Rectification: The process of converting the alternating voltages and currents to direct currents

Performance Parameters

$\eta = P_{dc} / P_{ac}$ **rectification effeciency**

$$V_{ac} = \sqrt{V_{rms}^2 - V_{dc}^2}$$

$FF = V_{rms} / V_{dc}$ **form factor**

ripple factor

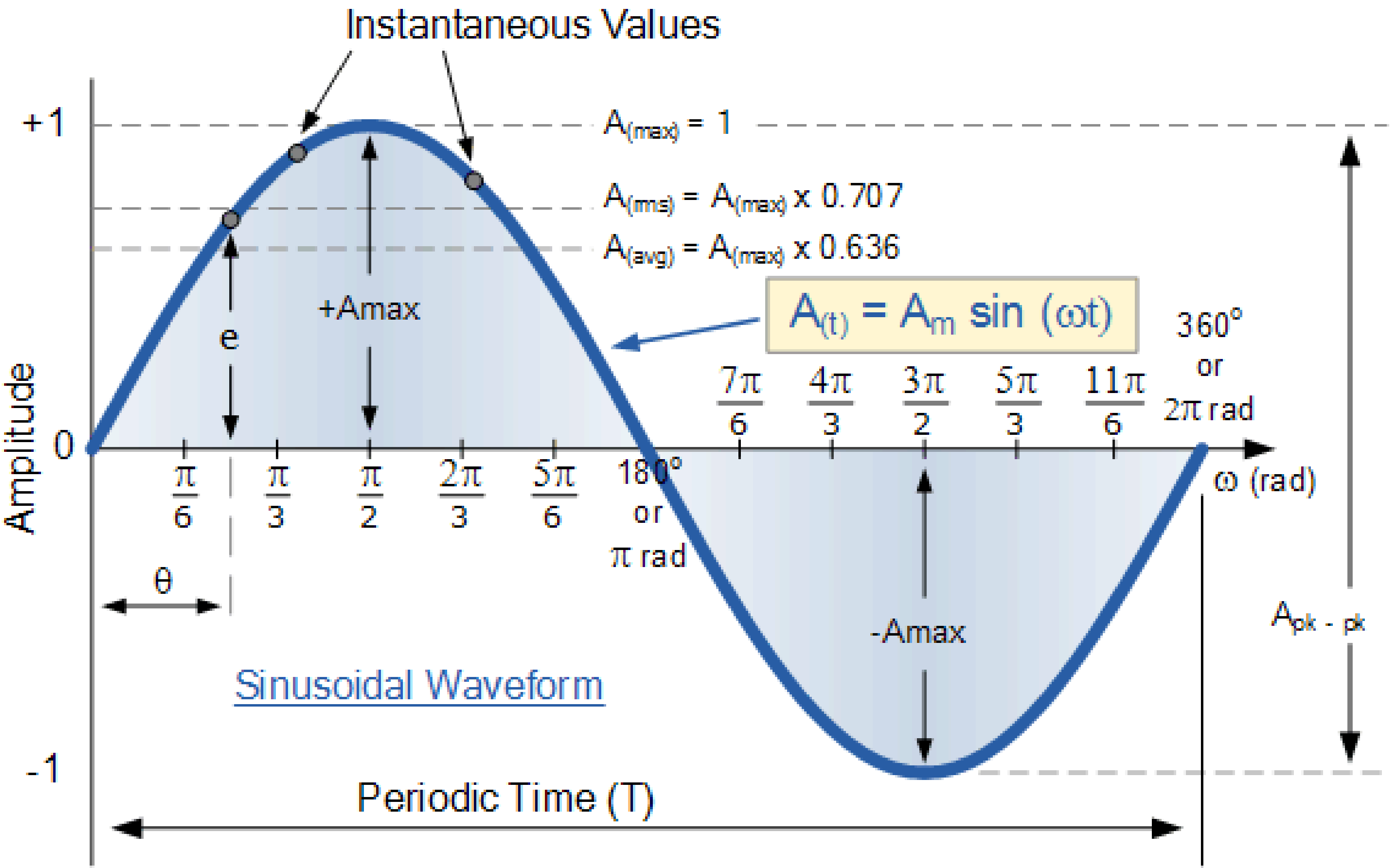
$$RF = \frac{V_{ac}}{V_{dc}} = \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}} = \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - 1} = \sqrt{FF^2 - 1}$$

$$THD_i = \sqrt{\frac{I_S^2 - I_{S1}^2}{I_{S1}^2}} = \sqrt{\frac{I_S^2}{I_{S1}^2} - 1}$$

$$THD_v = \sqrt{\frac{V_S^2 - V_{S1}^2}{V_{S1}^2}} = \sqrt{\frac{V_S^2}{V_{S1}^2} - 1}$$

$$PF = \frac{P}{V_S \ I_S} = \frac{V_S \ I_{S1} \cos\phi_1}{V_S \ I_S} = \frac{I_{S1}}{I_S} \cos\phi_1$$

$$= DistortionFactor * DisplacementFaactor$$



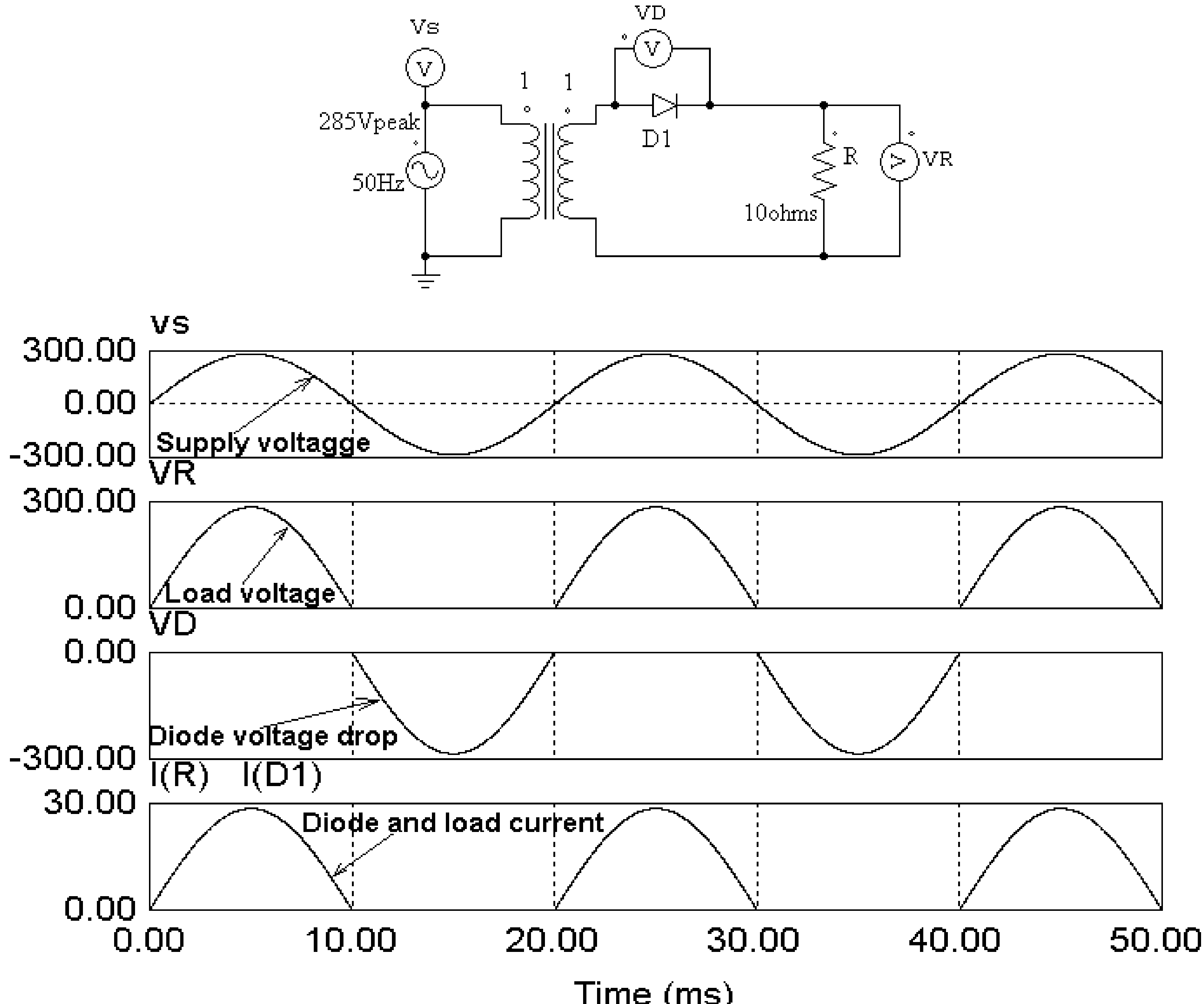
Important Equations to Remember

Vp x .707 = Vrms

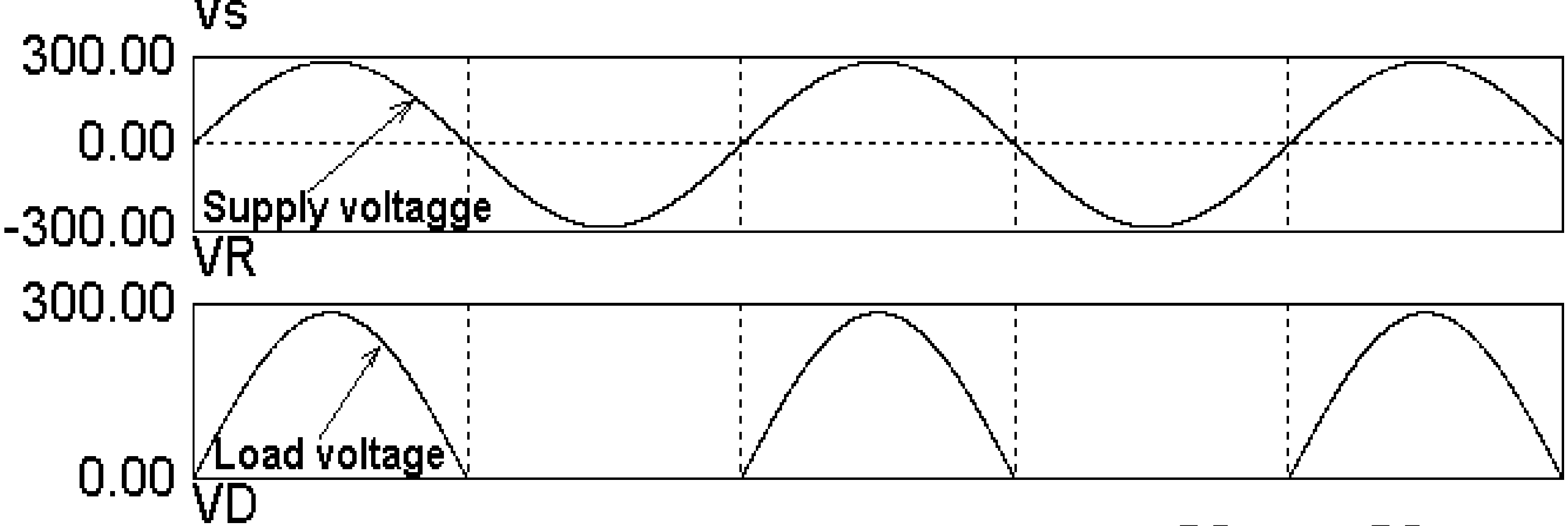
Vrms = 1.11 x Vavg

1.414 x Vrms= Vp

Vavg= .637 x Vp



Vs
VD
1
1
285Vpeak
50Hz
D1
R
VR
10ohms
vs
300.00
0.00
-300.00
Supply voltagge
VR
300.00
0.00
Load voltage
VD
0.00
-300.00
Diode voltage drop
I(R) I(D1)
30.00
0.00
Diode and load current
0.00
10.00
20.00
30.00
40.00
50.00
Time (ms)



$$V_{dc} = \frac{1}{2\pi}\int_0^{\pi} V_m \sin\omega t \; d\omega t = \frac{V_m}{\pi}$$

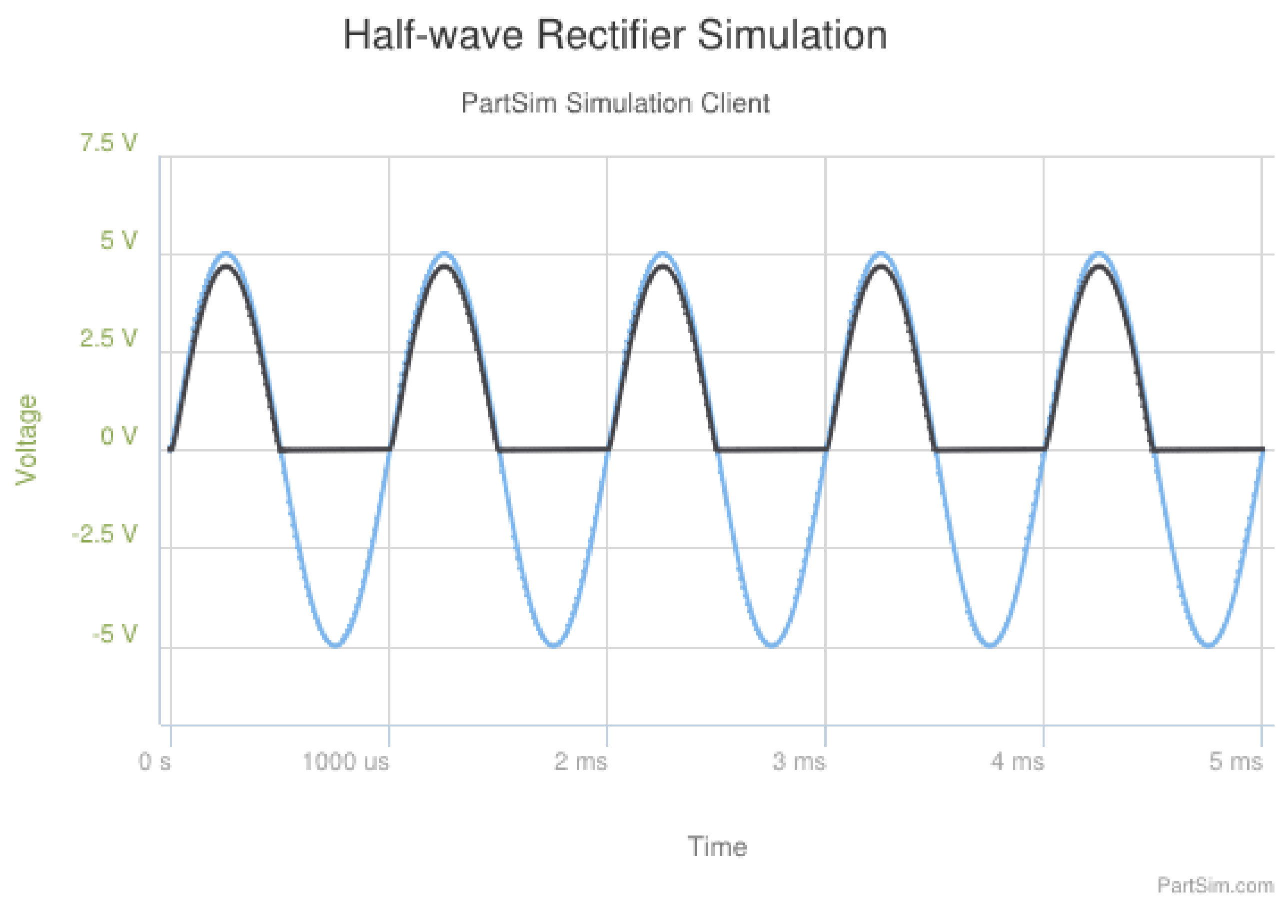
$$I_{dc} = \frac{V_{dc}}{R} = \frac{V_m}{\pi \; R}$$

$$V_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} V_m^2 \sin^2\omega t \; d\omega t} = \frac{V_m}{2}$$

$$I_{rms} = \frac{V_{rms}}{R} = \frac{V_m}{2\;R}$$

the load and diode currents

$$I_S = I_D = \frac{V_m}{2\;R}$$


Half-wave Rectifier Simulation
PartSim Simulation Client
7.5 V
5 V
2.5 V
0 V
-2.5 V
-5 V
Voltage
0 s
1000 us
2 ms
3 ms
4 ms
5 ms
Time
PartSim.com

The main disadvantages of half wave rectifier are:

- High ripple factor,
- Low rectification efficiency,
- Low transformer utilization factor, and,
- DC saturation of transformer secondary winding.

__Example 1:__ The rectifier shown in Fig.has a pure resistive load of *R* Determine (a) The efficiency, (b) Form factor (c) Ripple factor (d) Peak inverse voltage (PIV) of diode D1.

$$V_{dc} = \frac{1}{2\pi}\int_0^{\pi} V_m \sin(\omega t)\, d\omega t = \frac{V_m}{2\pi}(-\cos\pi - \cos(0)) = \frac{V_m}{\pi} \qquad I_{dc} = \frac{V_{dc}}{R} = \frac{V_m}{\pi R}$$

$$V_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} (V_m \sin\, \omega t)^2} = \frac{V_m}{2} \qquad I_{rms} = \frac{V_m}{2\, R}$$

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{V_{dc} * I_{dc}}{V_{rms} * I_{rms}} = \frac{\frac{V_m}{\pi} * \frac{V_m}{\pi R}}{\frac{V_m}{2} * \frac{V_m}{2R}} = 40.53\%$$

.

$$FF = \frac{V_{rms}}{V_{dc}} = \frac{\frac{V_m}{2}}{\frac{V_m}{\pi}} = \frac{\pi}{2} = 1.57$$

$$RF = \frac{V_{ac}}{V_{dc}} = \sqrt{FF^2 - 1} = \sqrt{1.57^2 - 1} = 1.211$$

(d) It is clear from Fig. that the PIV is V_m

Consider the half-wave rectifier circuit of with a resistive load of 25 Ω and a 60 Hz ac source of 110 V rms.

(a) Calculate the average values of v_o and i_o.

(b) Calculate the rms values of v_o and i_o.

(c) Calculate the average power delivered to the load.

$$V_o = \frac{V_s}{\pi}$$

$$= 49.52 \text{ V}$$

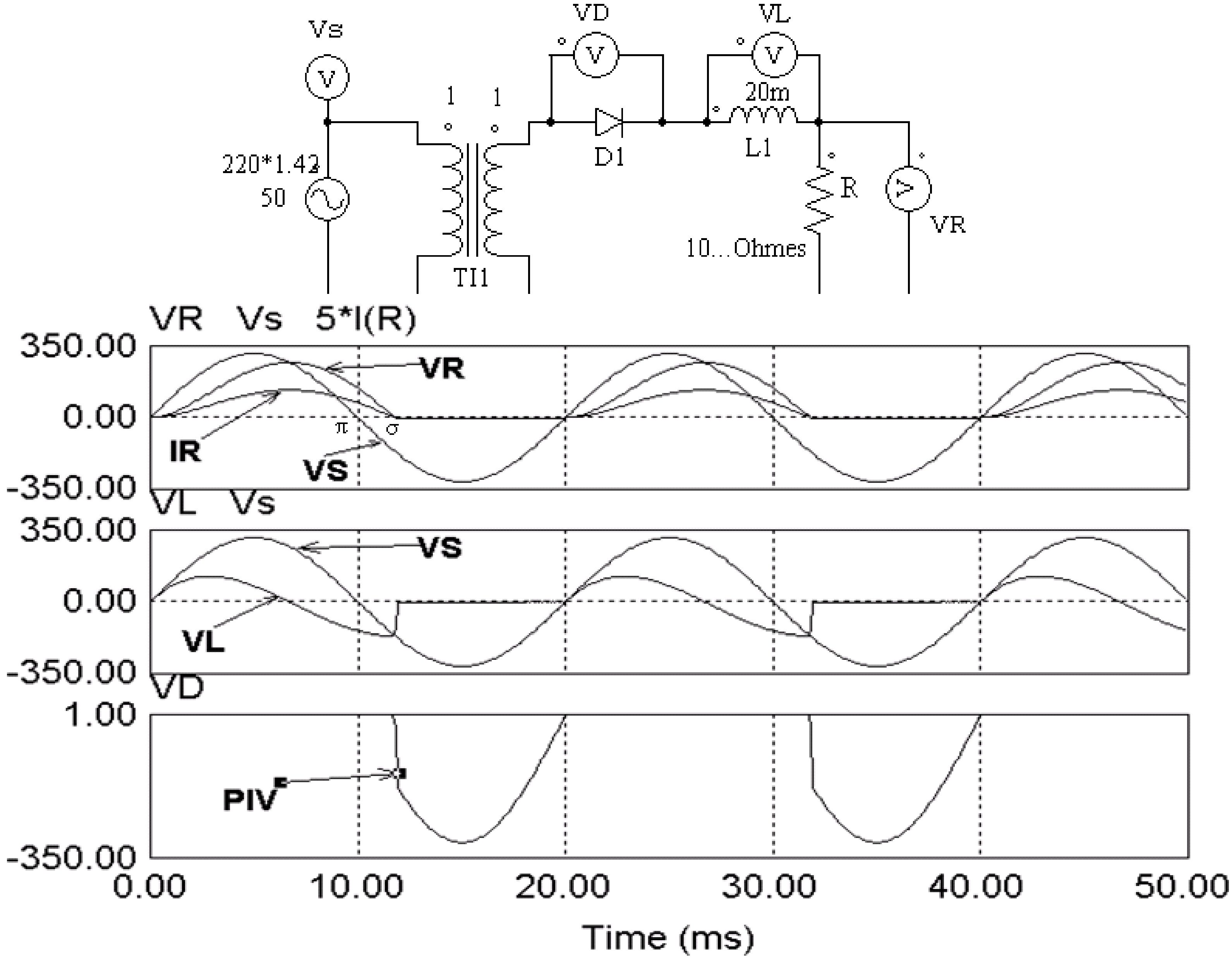
$$I_o = \frac{V_o}{R}$$

$$= 1.98 \text{ A}$$

$$P_o = \frac{V_{o,\text{rms}}^2}{R}$$

$$= 242 \text{ W}$$

Half Wave Diode Rectifier With R-L Load



- The operation of the circuit is as follows:
- As in the case of a resistive load, the diode turns on when its anode is positive w.r.t its cathode, and the foward voltage is greater than the threshold voltage.
- Assuming a turn-on voltage of zero volts, the voltage across the load is the same as the positive half cycle of the ac source.

During the interval 0 to Π/2

- The source voltage $\mathbf{v}_s$ increases from zero to its positive maximum, while the voltage across the inductor $\mathbf{v}_L$ opposes the change of current through the load.
- It must be noted that the current through an inductor cannot change instantaneously, hence the current gradually increases until it reaches its maximum value.
- The current does not reach its peak when the voltage is at its maximum, which is consistent with the fact that the current through an inductor lags the voltage across it.
- During this time, energy is transferred from the ac source and is stored in the magnetic field of the inductor.

For the interval Π/2 and Π

- The source voltage decreases from its positive maximum to zero. The induced voltage in the inductor reverses polarity and opposes the associated decrease in current, thereby aiding the diode forward current.
- Therefore, the current starts decreasing gradually at a delayed time, becoming zero when all the energy stored by then inductor is released to the circuit. Again this is consistent with the fact that current lags voltage in an inductive circuit. Hence, even after the source voltage has dropped past zero volts, there is still load current, which exists a little more than half a cycle.

For the interval greater than Π

- At θ, the source voltage reverses and starts to increase to its negative maximum. However, the voltage induced across the inductor is still positive and will sustain forward conduction of the diode until this induced voltage decreases to zero. When this induced voltage falls to zero, the diode will now be reversed biased, but would have conducted forward current for an angle θ, where $\theta = \Pi + \sigma$. s is the extended angle of current conduction due to the energy stored in the magnetic field being returned to the source.

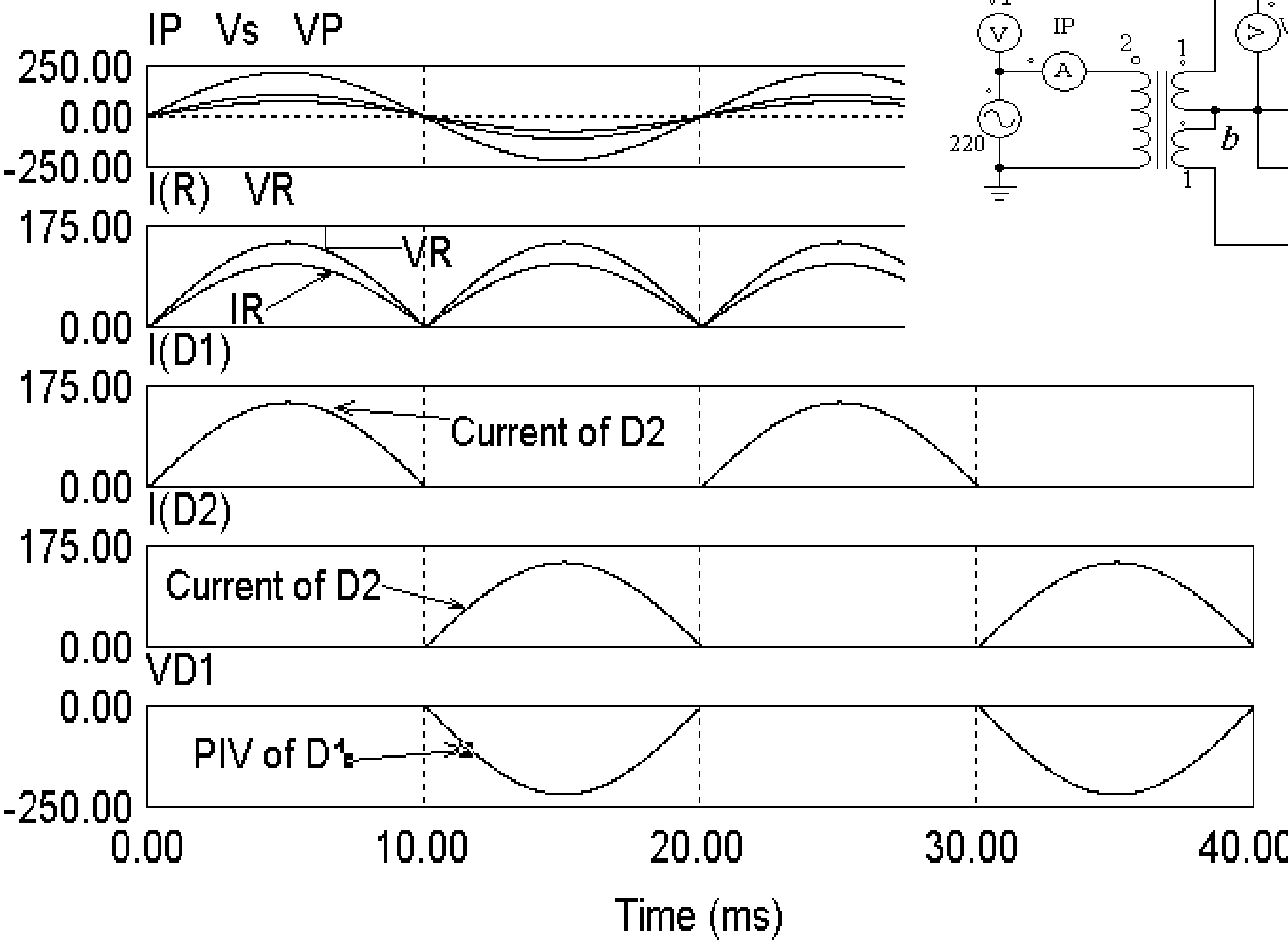
$$V_{dc} = \frac{V_m}{2\pi} * \int_0^{\beta} \sin\ \omega t\ d\omega t = \frac{V_m}{2\pi} * (1 - \cos\ \beta)$$

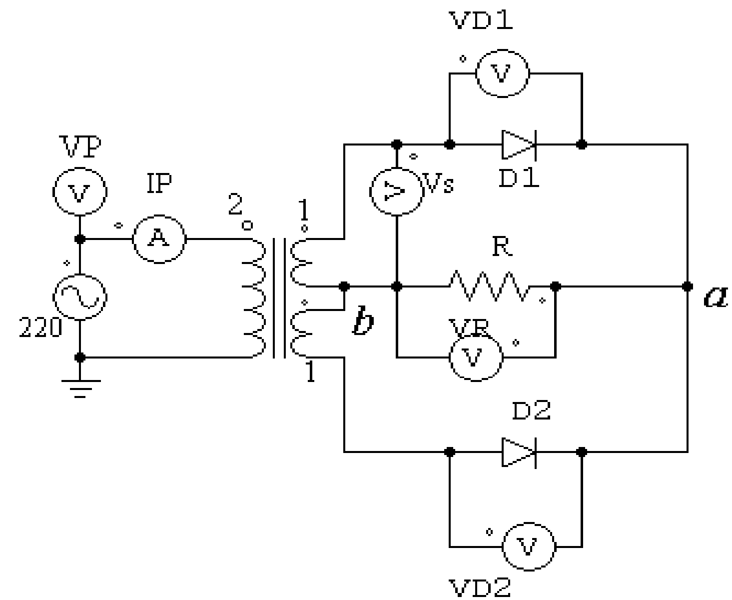
$$Where, \beta = (\pi + \sigma)$$

$$V_{rms} = \sqrt{\frac{1}{2\pi} * \int_0^{\beta} (V_m \sin\ \omega t)^2\ dwt} = \frac{Vm}{2\sqrt{\pi}} * \sqrt{\beta + 0.5(1 - \sin(2\beta)}$$

Single-Phase Full-Wave Diode Rectifier

Center-Tap Diode Rectifier





$$V_{dc} = \frac{1}{\pi}\int_0^{\pi} V_m \sin\omega t \; d\omega t = \frac{2V_m}{\pi}$$

$$I_{dc} = \frac{2V_m}{\pi \; R}$$

$$V_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} \left(V_m \sin\omega t\right)^2 \; d\omega t} = \frac{V_m}{\sqrt{2}}$$

$$I_{rms} = \frac{V_m}{\sqrt{2} \; R}$$

PIV of each diode = $2V_m$

$$I_S = I_D = \frac{V_m}{2 \; R}$$

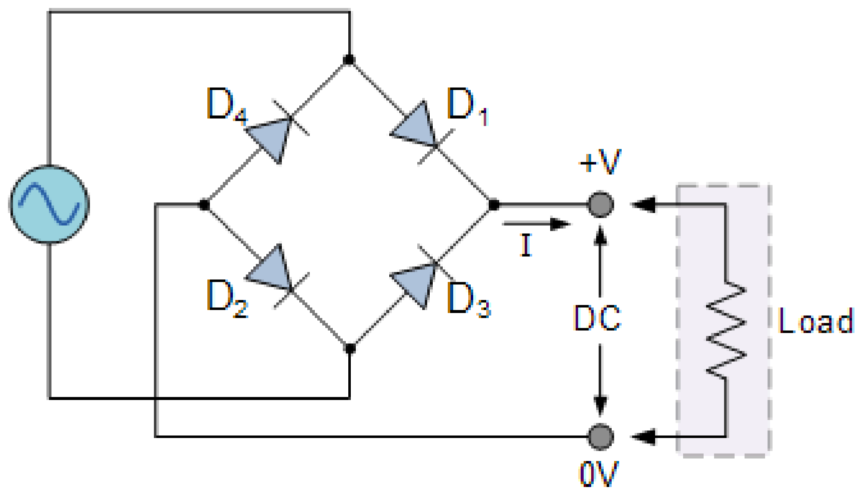
Example 3. The rectifier in Fig.2.8 has a purely resistive load of *R* Determine (a) The efficiency, (b) Form factor (c) Ripple factor (d) TUF (e) Peak inverse voltage (PIV) of diode D1

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{V_{dc} * I_{dc}}{V_{rms} * I_{rms}} = \frac{\frac{2\,V_m}{\pi} * \frac{2\,V_m}{\pi\,R}}{\frac{V_m}{\sqrt{2}} * \frac{V_m}{\sqrt{2}\,R}} = 81.05\%$$

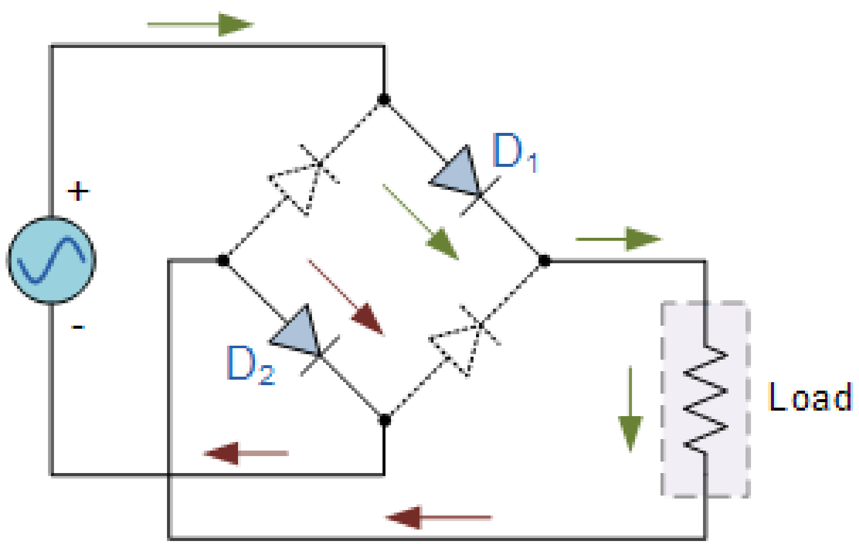
$$FF = \frac{V_{rms}}{V_{dc}} = \frac{\frac{V_m}{\sqrt{2}}}{\frac{2\,V_m}{\pi}} = \frac{\pi}{2\sqrt{2}} = 1.11$$

$$RF = \frac{V_{ac}}{V_{dc}} = \sqrt{FF^2 - 1} = \sqrt{1.11^2 - 1} = 0.483$$

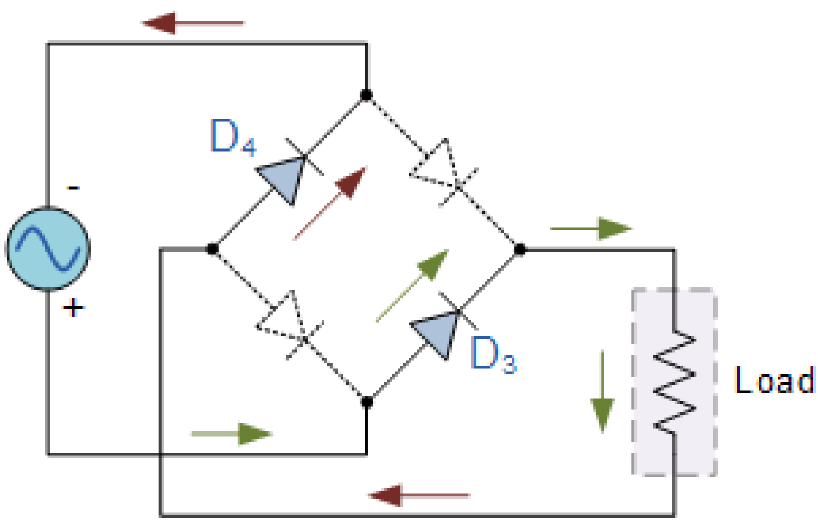
The PIV is $2V_m$



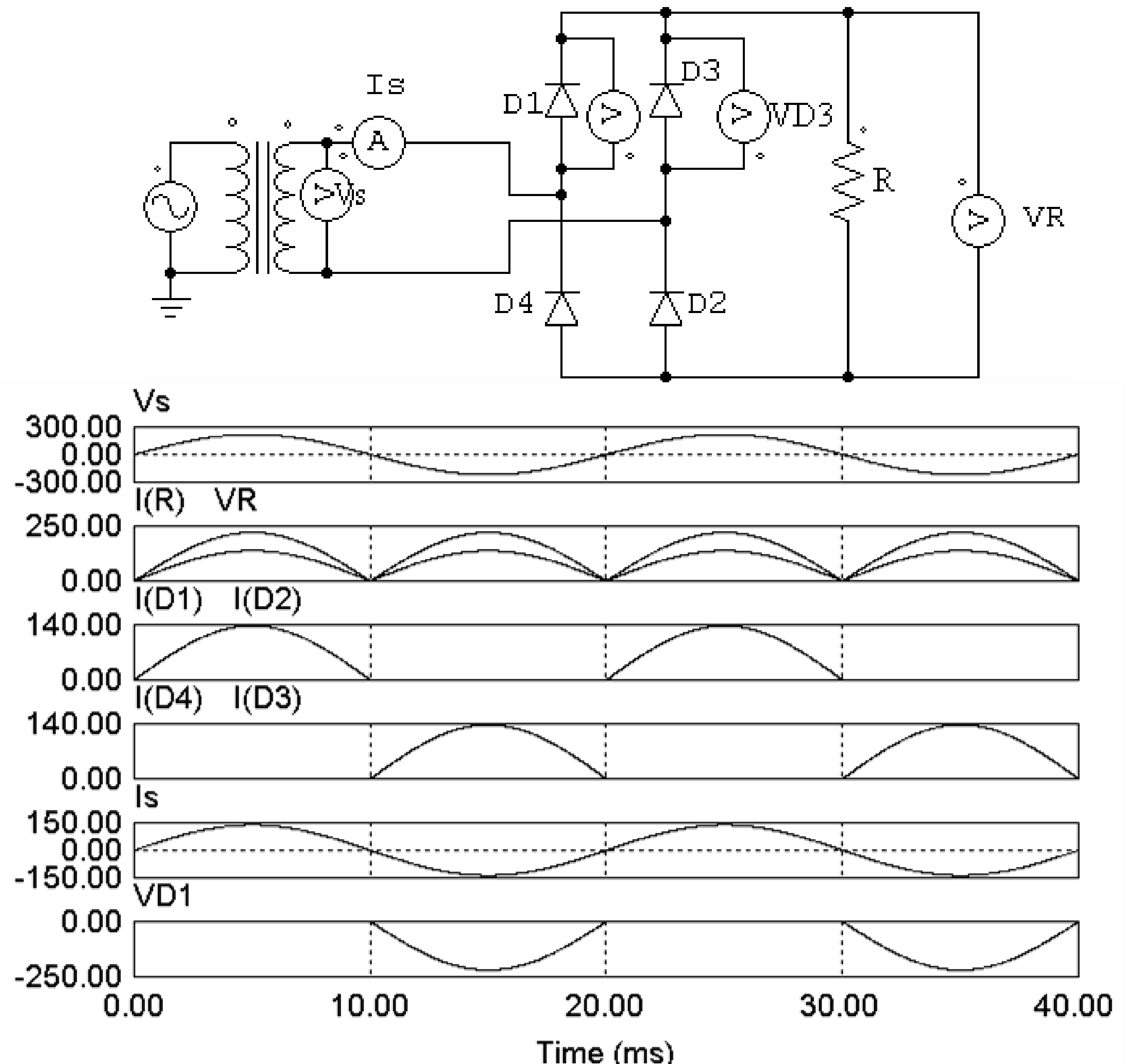
Positive Half-cycle



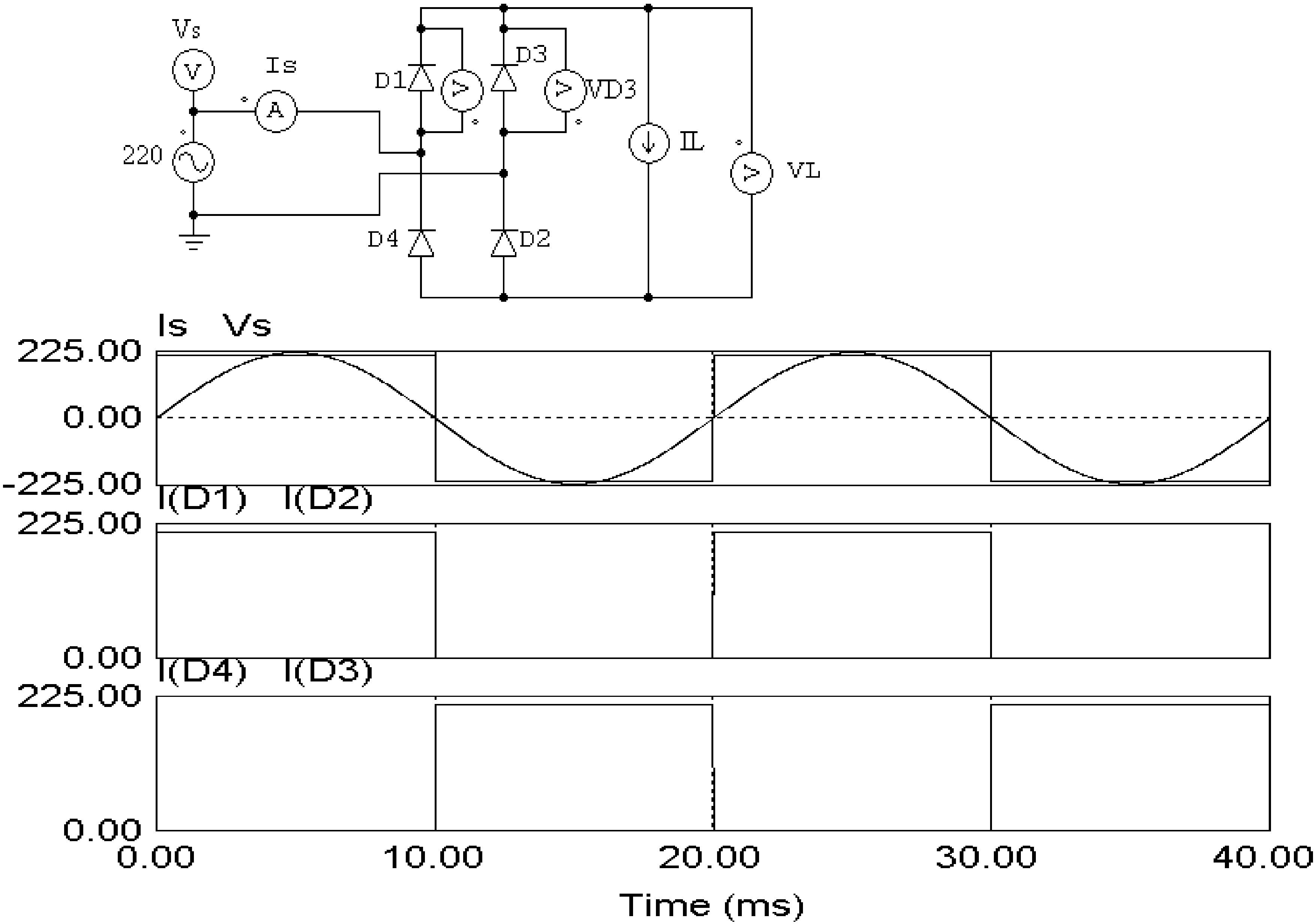
Negative Half-cycle



Single-Phase Full Bridge Diode Rectifier With Resistive Load



Full Bridge Single-phase Diode Rectifier with DC Load Current



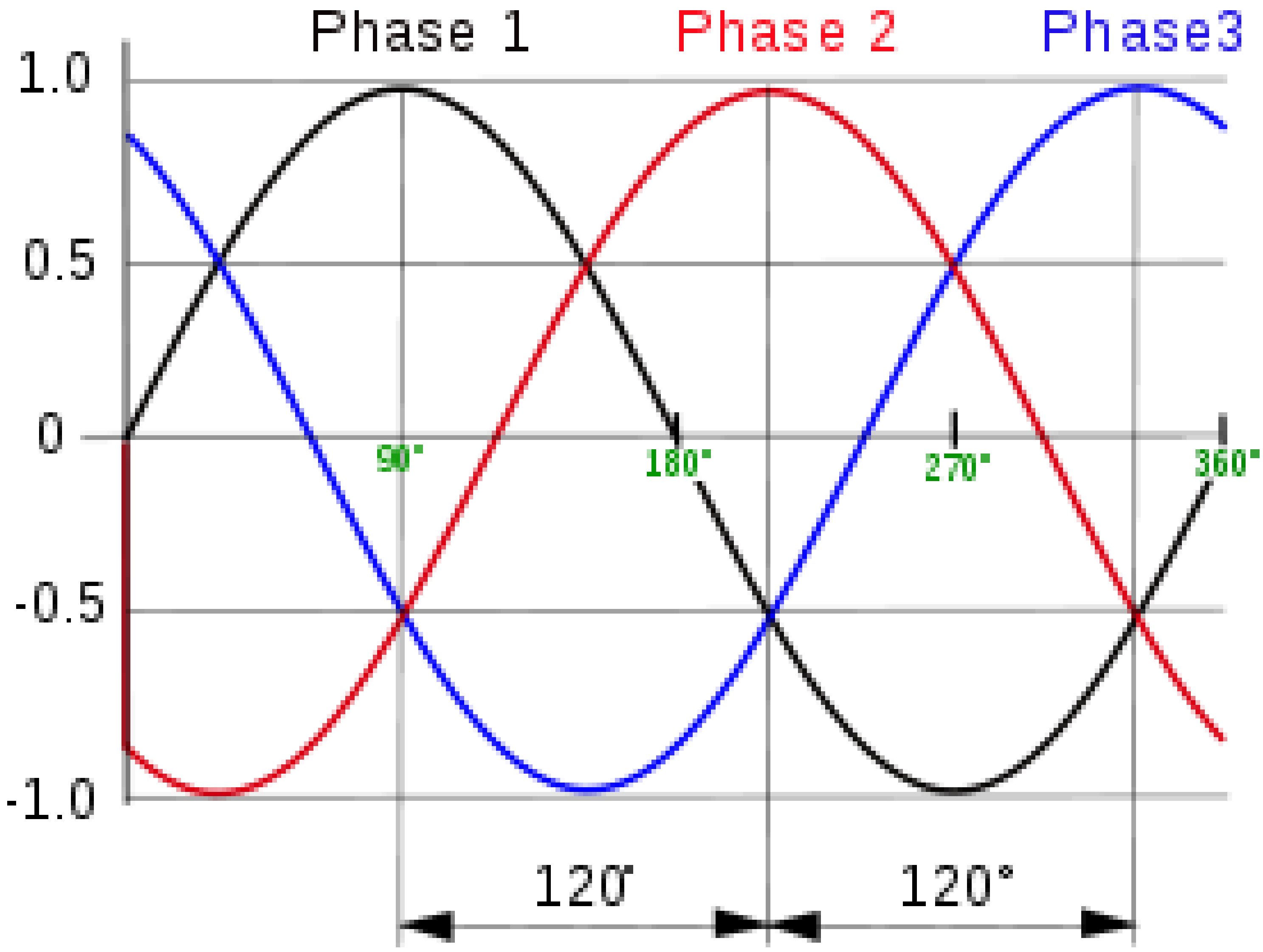
The Full Wave Bridge Rectifier

This type of single phase rectifier uses four individual rectifying diodes connected in a closed loop “bridge” configuration to produce the desired output.

The main advantage of this bridge circuit is that it does not require a special centre tapped transformer, thereby reducing its size and cost. The single secondary winding is connected to one side of the diode bridge network and the load to the other side as shown below.

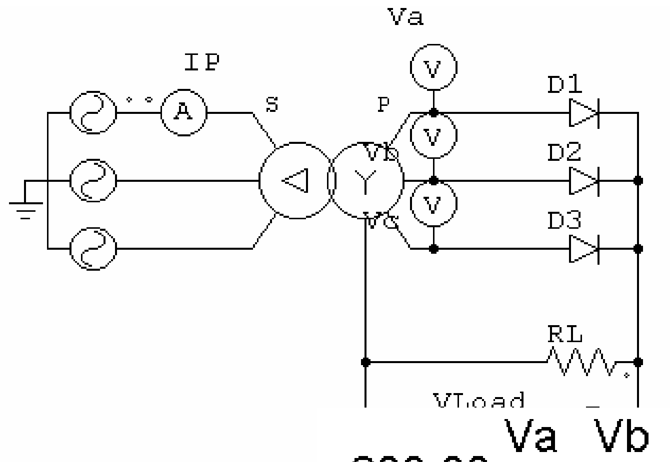
COMPARISON OF SINGLE PHASE RECTIFIER

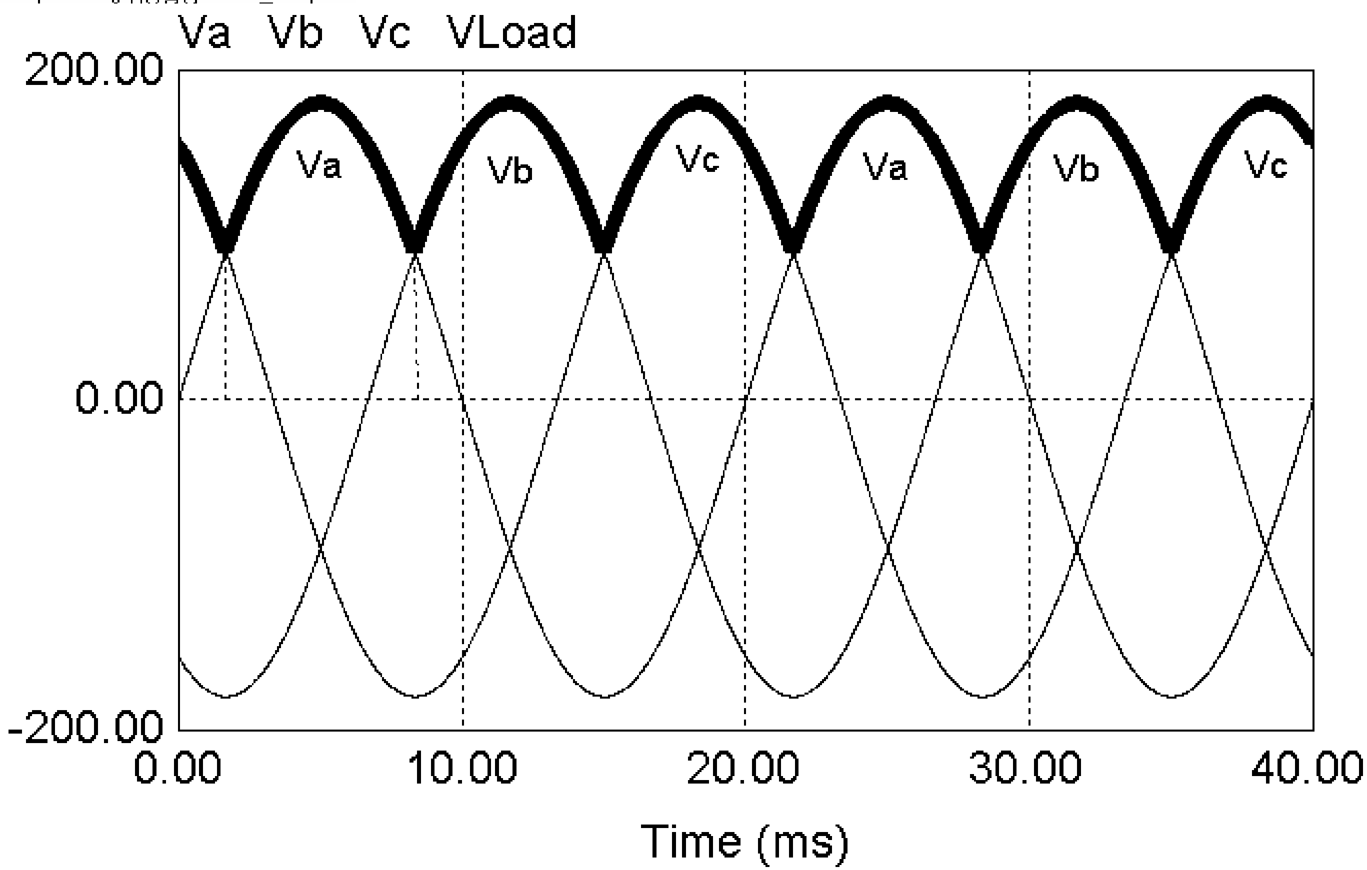
Sr. No.	Parameters	Half-wave	Full-wave	
			Centre-tap	Bridge
1	DC output Voltage, Vo	Vm/π	2Vm/π	2Vm/π
2	Rms value of output Voltage, Vor	Vm/2	Vm/1.41	Vm/1.41
3	Ripple Voltage, Vr	0.3856 Vm	0.3077 Vm	0.3077 Vm
4	Voltage ripple Factor, VRF	1.211	0.482	0.482
5	Efficiency	40.53%	81.06%	81.06%
6	TUF	0.2865	0.672	0.8106
7	PIV	Vm	2Vm	Vm
8	Number of Diode	1	2	4
9	Ripple frequency	f	2f	2f

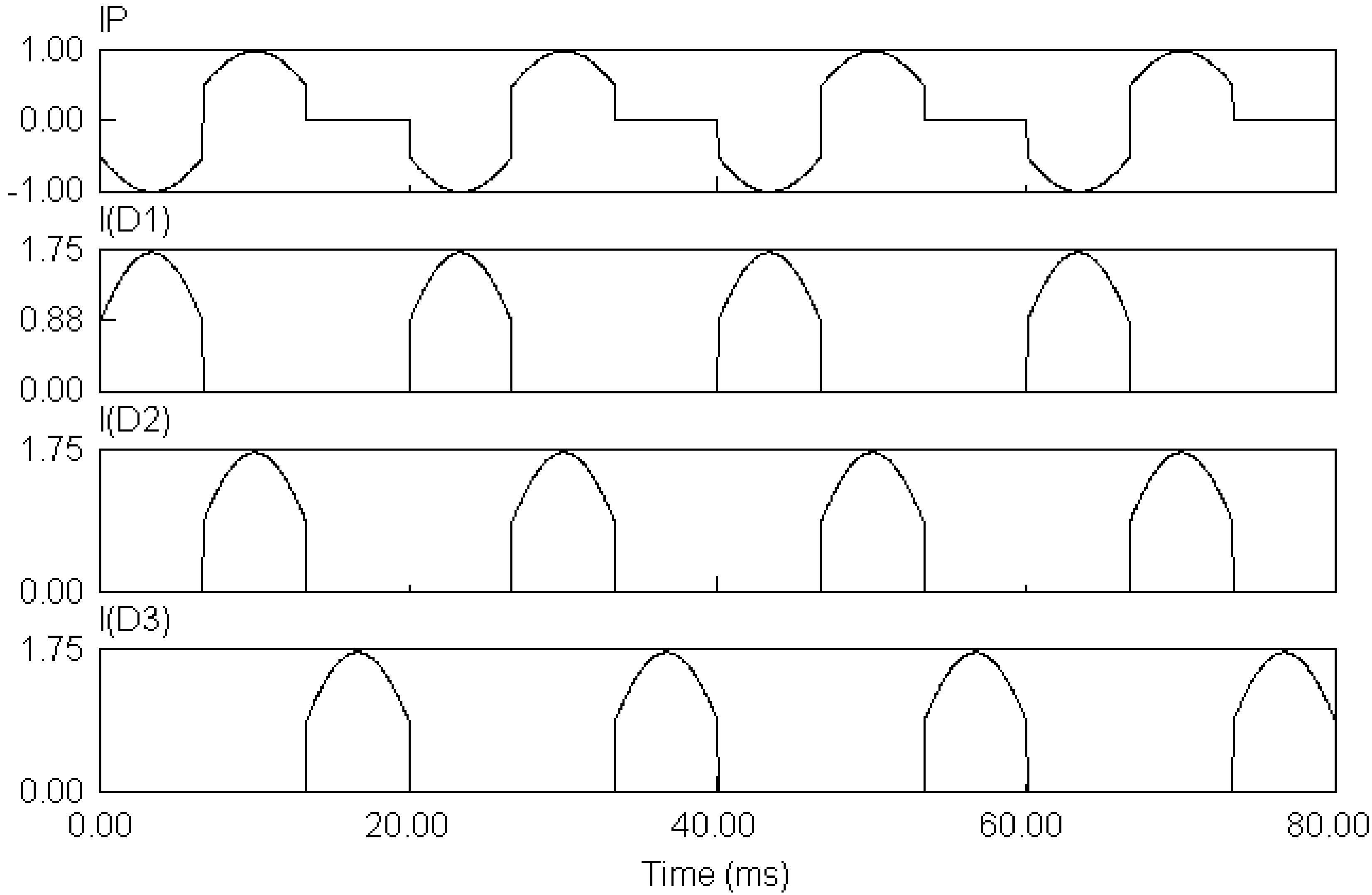


Phase 1
Phase 2
Phase3
1.0
0.5
0
-0.5
-1.0
90°
180°
270°
360°
120°
120°

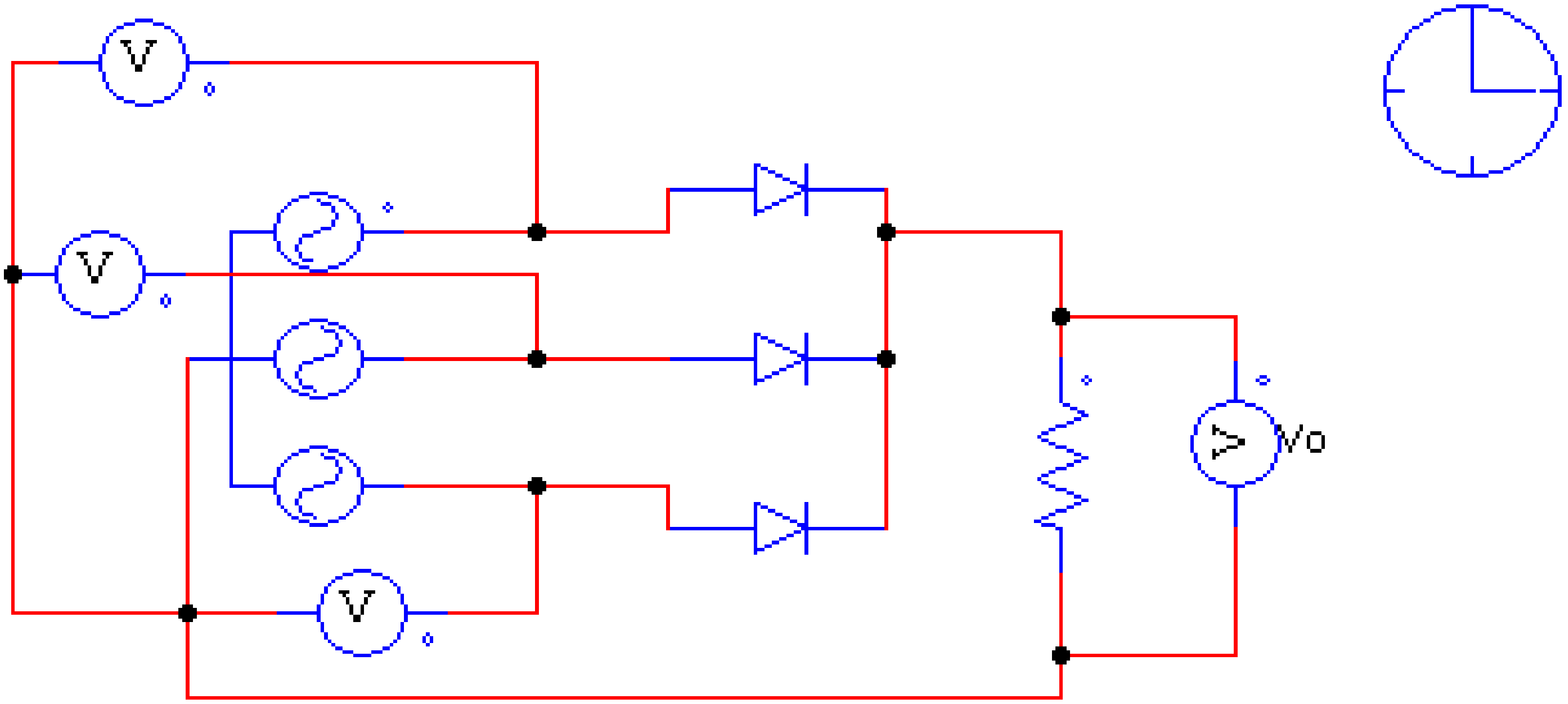
Three-Phase Half Wave Rectifier



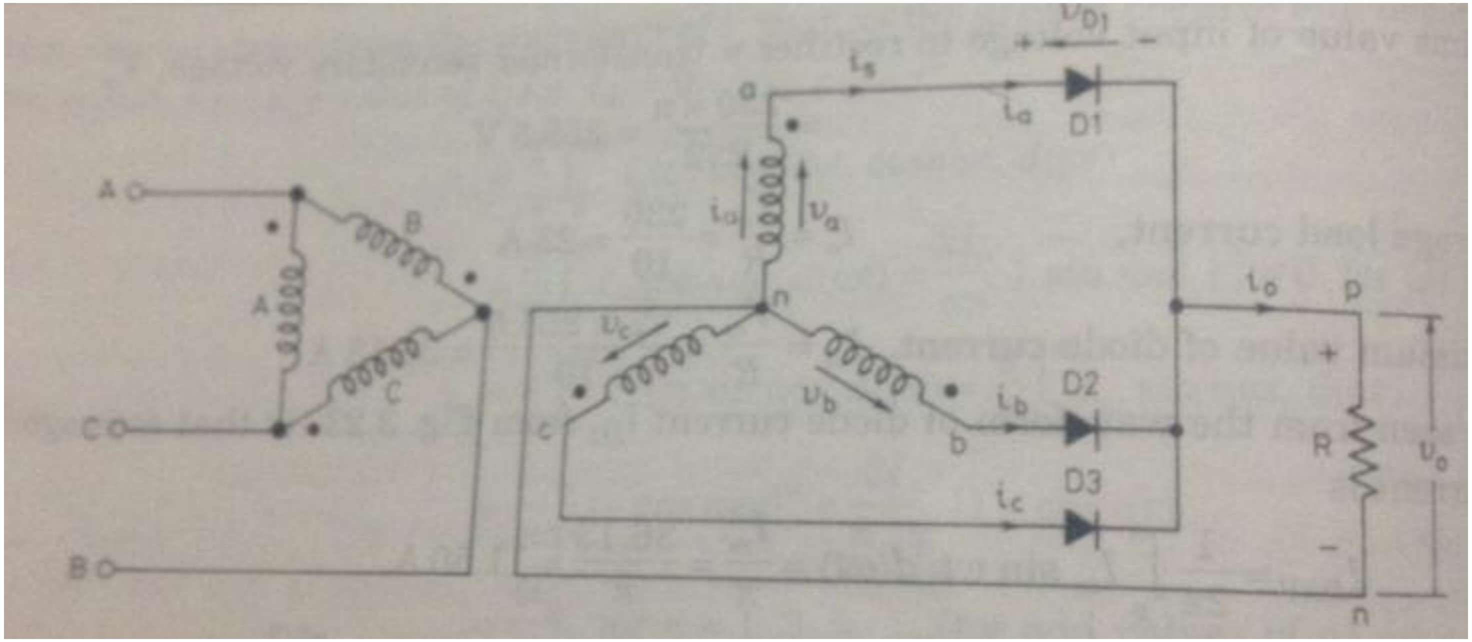




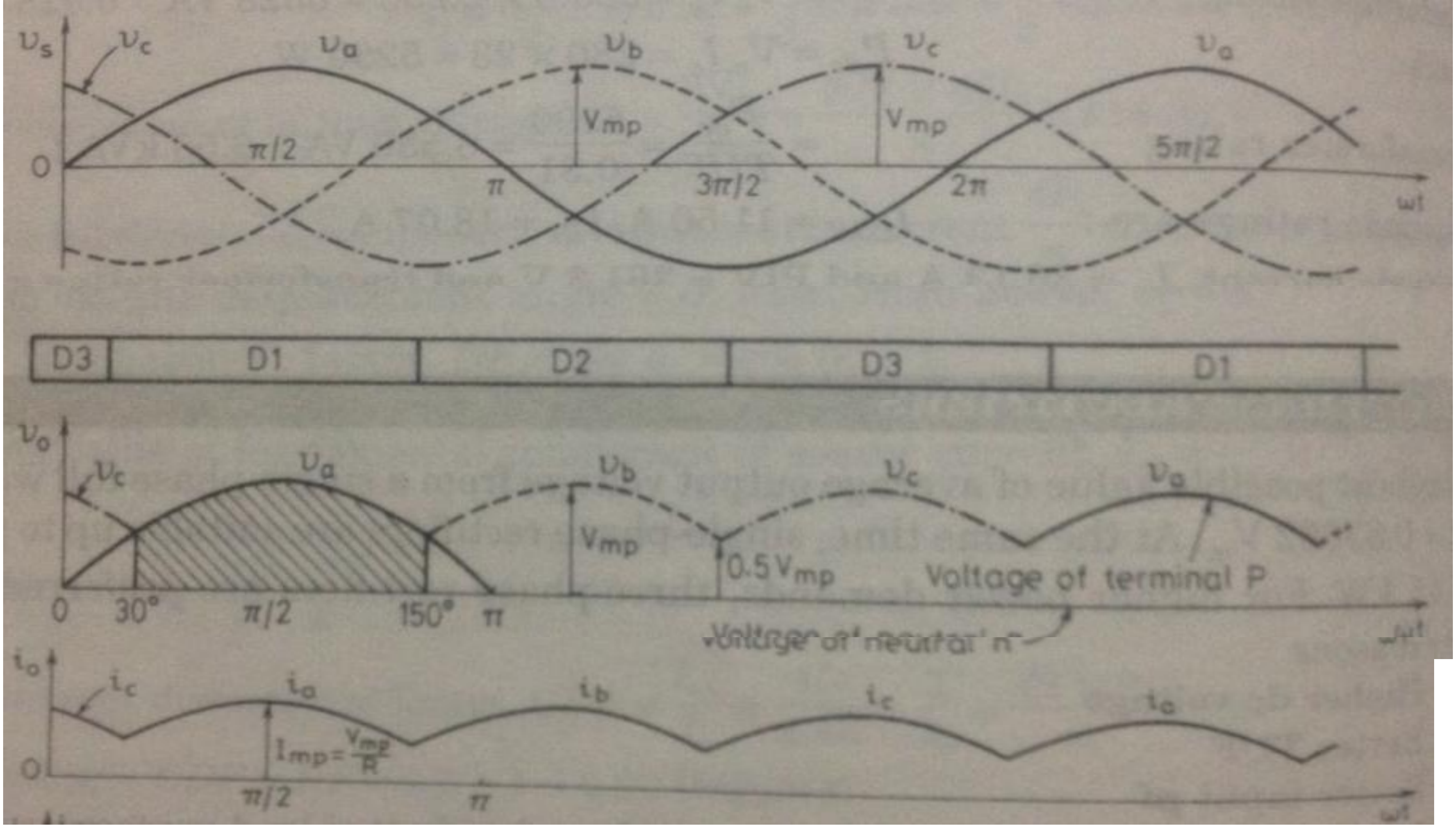
IP
1.00
0.00
-1.00
I(D1)
1.75
0.88
0.00
I(D2)
1.75
0.00
I(D3)
1.75
0.00
0.00
20.00
40.00
60.00
80.00
Time (ms)



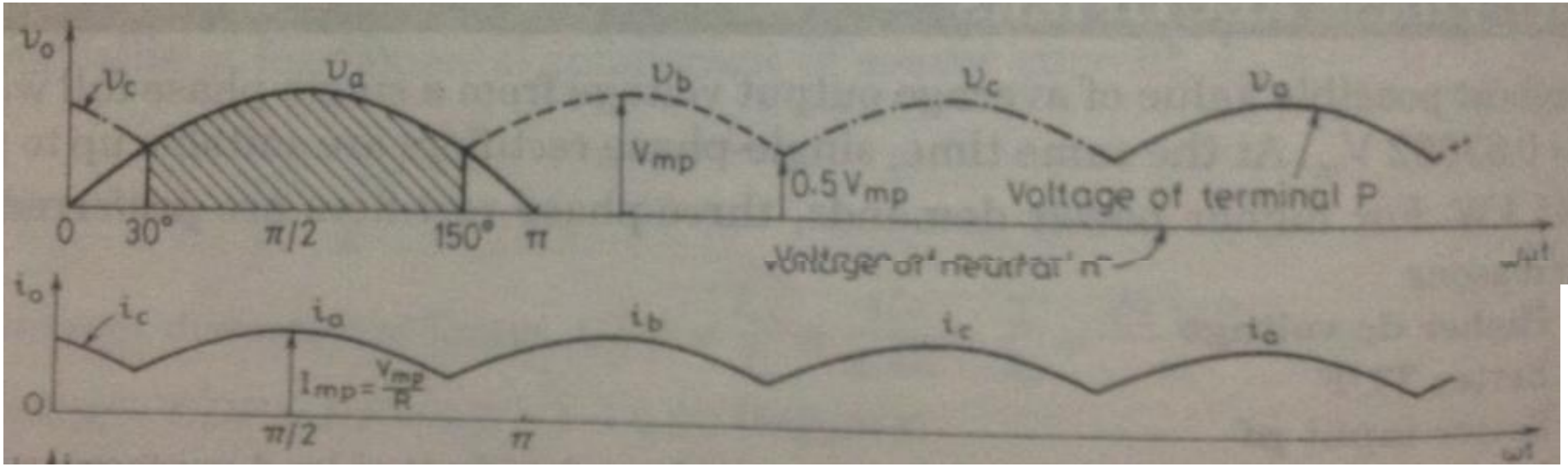
V
V
V
Vo



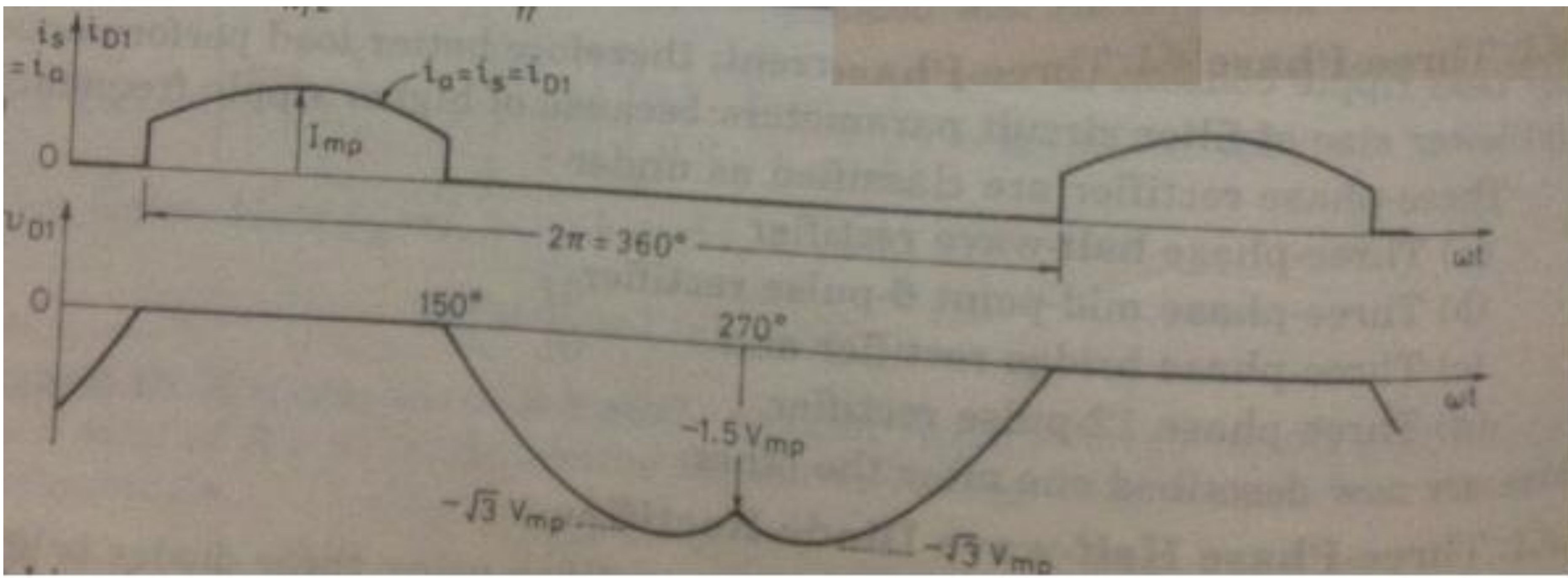
v_{D1}
D1
D2
D3
R
v_o
i_o
i_a
i_b
i_c
v_a
v_b
v_c
A
B
C
a
b
c
n
p



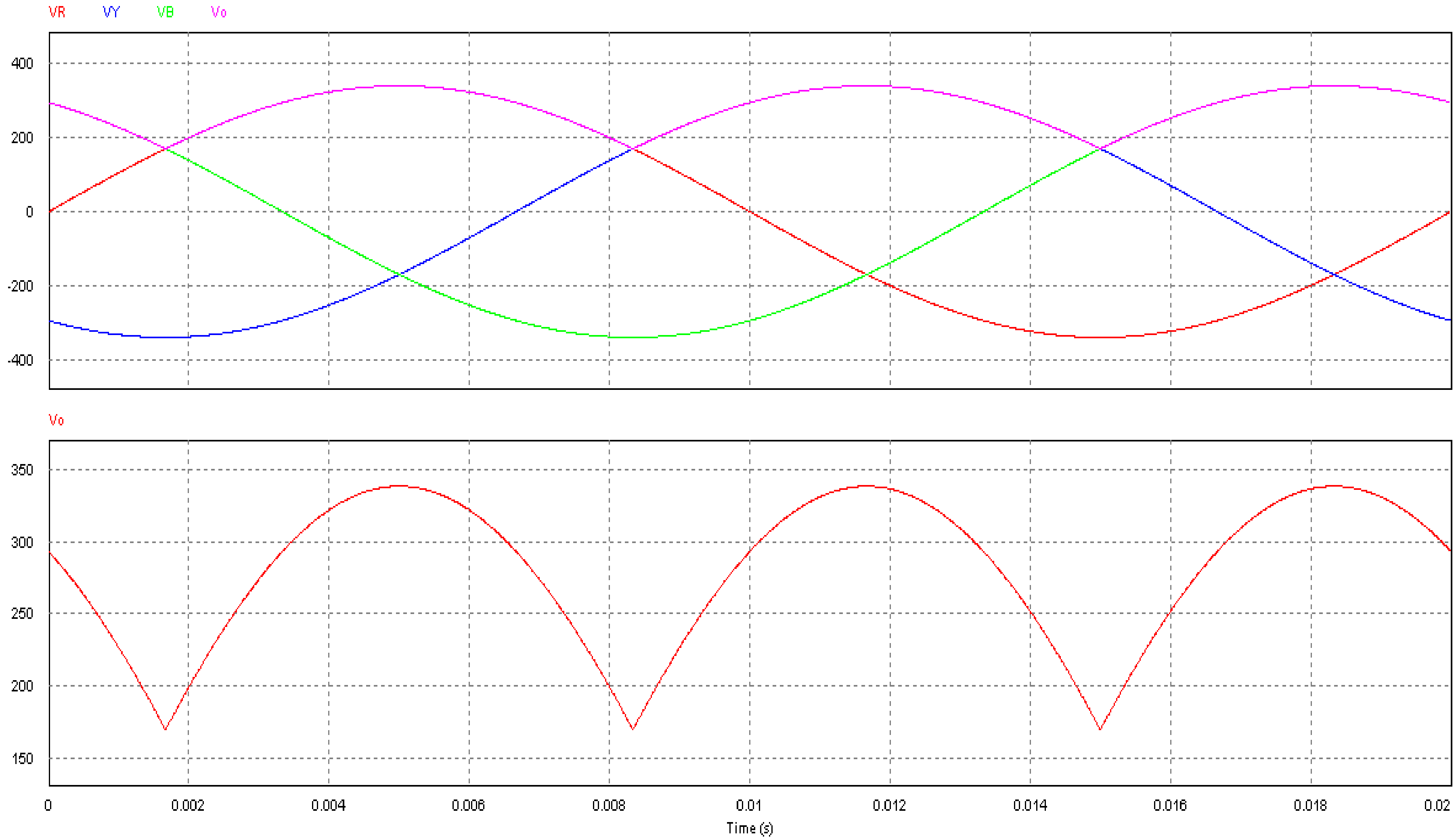
v_s
v_c
v_a
v_b
v_c
v_a
V_{mp}
V_{mp}
0
$\pi/2$
π
$3\pi/2$
2π
$5\pi/2$
ωt
D3
D1
D2
D3
D1
v_o
v_c
v_a
v_b
v_c
v_a
V_{mp}
$0.5V_{mp}$
Voltage of terminal P
0
30°
$\pi/2$
150°
π
Voltage of neutral n
ωt
i_o
i_c
i_a
i_b
i_c
i_a
$I_{mp}=\frac{V_{mp}}{R}$
0
$\pi/2$
π
ωt



v_o
v_c
v_a
v_b
v_c
v_a
V_{mp}
$0.5 V_{mp}$
Voltage of terminal P
0
30°
π/2
150°
π
Voltage of neutral n
ωt
i_o
i_c
i_a
i_b
i_c
i_a
$I_{mp} = \frac{V_{mp}}{R}$
0
π/2
π
ωt



i_s
i_{D1}
$= i_a$
$i_a = i_s = i_{D1}$
I_{mp}
0
$2\pi = 360°$
ωt
v_{D1}
0
150°
270°
ωt
$-1.5 V_{mp}$
$-\sqrt{3} V_{mp}$
$-\sqrt{3} V_{mp}$



VR
VY
VB
Vo
400
200
0
-200
-400
Vo
350
300
250
200
150
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02
Time (s)

$$V_{dc} = \frac{3}{2\pi} \int_{\pi/6}^{5\pi/6} V_m \sin \omega t \; d\omega t = \frac{3\sqrt{3}\; V_m}{2\pi} = 0.827 V_m$$

$$I_{dc} = \frac{3\sqrt{3}\; V_m}{2 * \pi * R} = \frac{0.827 * V_m}{R}$$

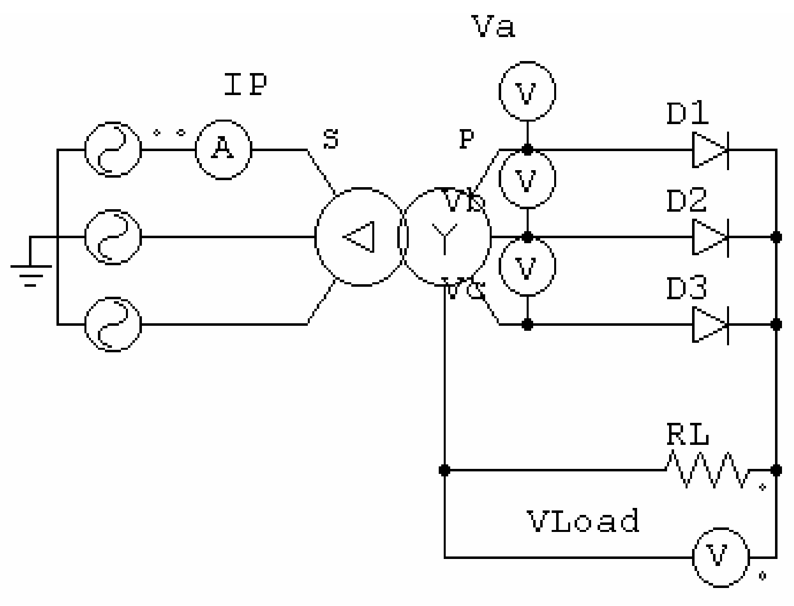
$$V_{rms} = \sqrt{\frac{3}{2\pi} \int_{\pi/6}^{5\pi/6} (V_m \sin \omega t\;)^2 \, d\omega t} = \sqrt{\frac{1}{2} + \frac{3 * \sqrt{3}}{8\;\pi}}\, V_m = 0.8407\; V_m$$

$$I_{rms} = \frac{0.8407\;\; V_m}{R}$$

$$I_r = I_S = \frac{08407\;\; V_m}{R\;\sqrt{3}} = 0.4854\;\; \frac{V_m}{R}$$

ThePIV of the diodes is $= \sqrt{3}\; V_m$

Example 7 The rectifier in below is operated from 460 V 50 Hz supply at secondary side and the load Ω resistance is *R*=20. If the source inductance is negligible, determine (a) Rectification efficiency, (b) Form factor (c) Ripple factor (d) Peak inverse voltage (PIV) of each diode.



$$V_S = \frac{460}{\sqrt{3}} = 265.58 \ \ V, \quad V_m = 265.58 * \sqrt{2} = 375.59 \ \ V$$

$$V_{dc} = \frac{3\sqrt{3} \ \ V_m}{2\pi} = 0.827 \ V_m \qquad I_{dc} = \frac{3\sqrt{3} \ \ V_m}{2\,\pi \ \ R} = \frac{0827\,V_m}{R}$$

$$V_{rms} = 0.8407 \ \ V_m \qquad I_{rms} = \frac{0.8407 \ \ V_m}{R}$$

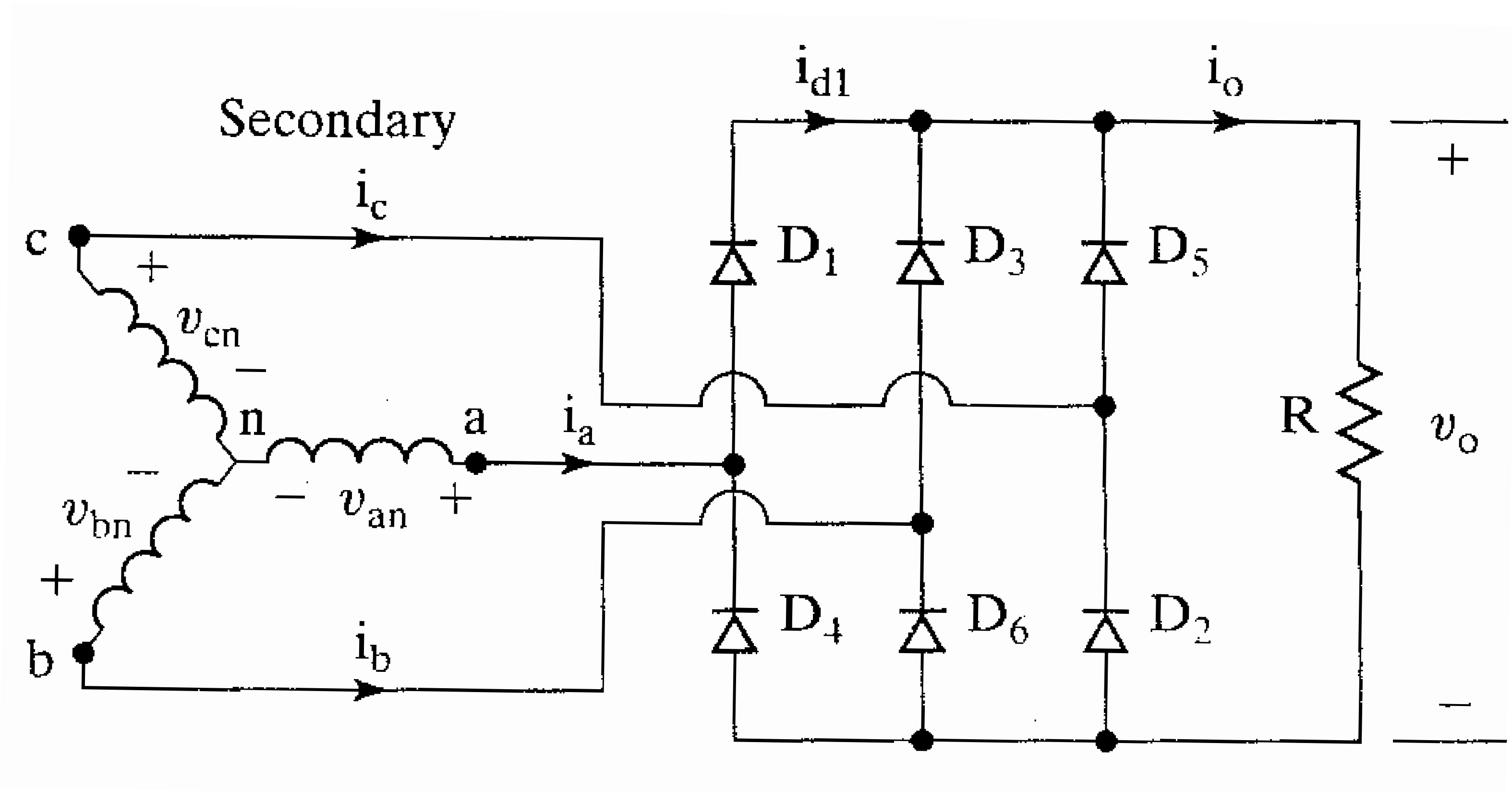
$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{V_{dc}\,I_{dc}}{V_{rms}\,I_{rms}} = 96.767 \ \ \%$$

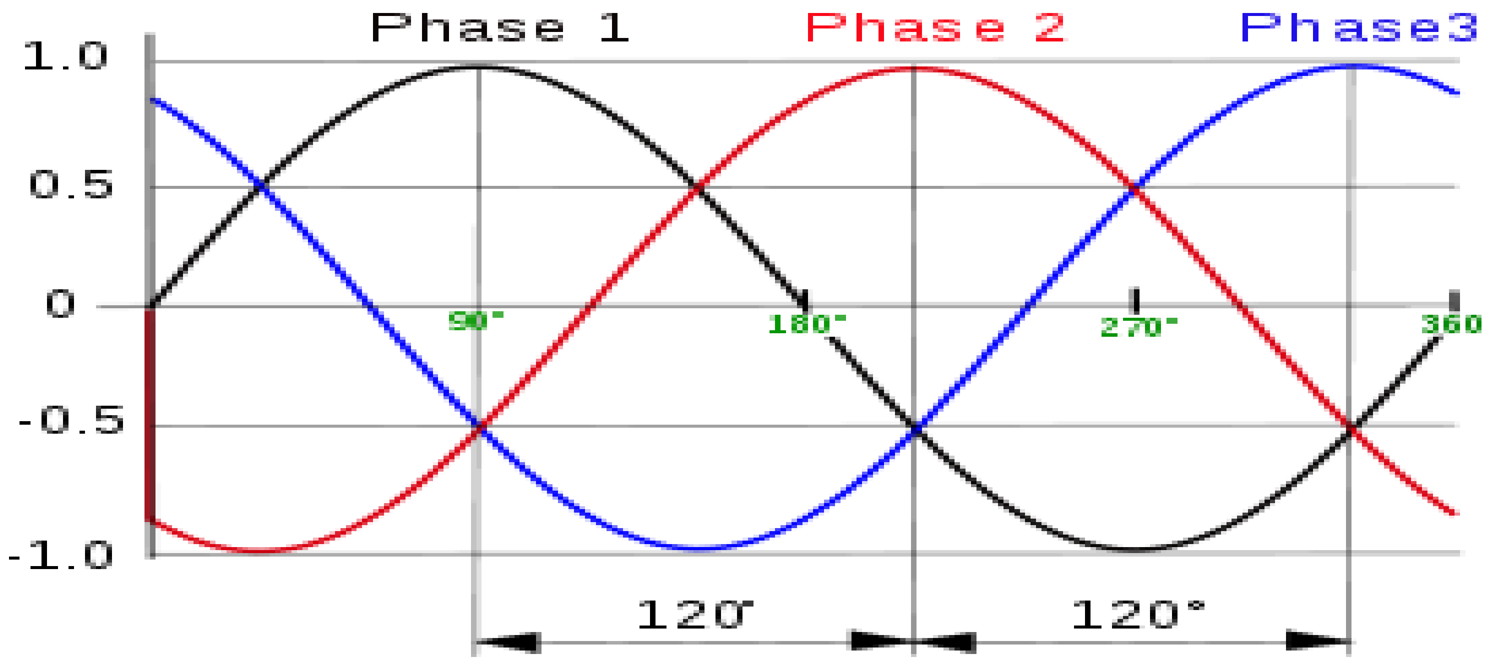
$$FF = \frac{V_{rms}}{V_{dc}} = 101.657 \ \%$$

$$RF = \frac{V_{ac}}{V_{dc}} = \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}} = \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - 1} = \sqrt{FF^2 - 1} = 18.28 \ \ \%$$

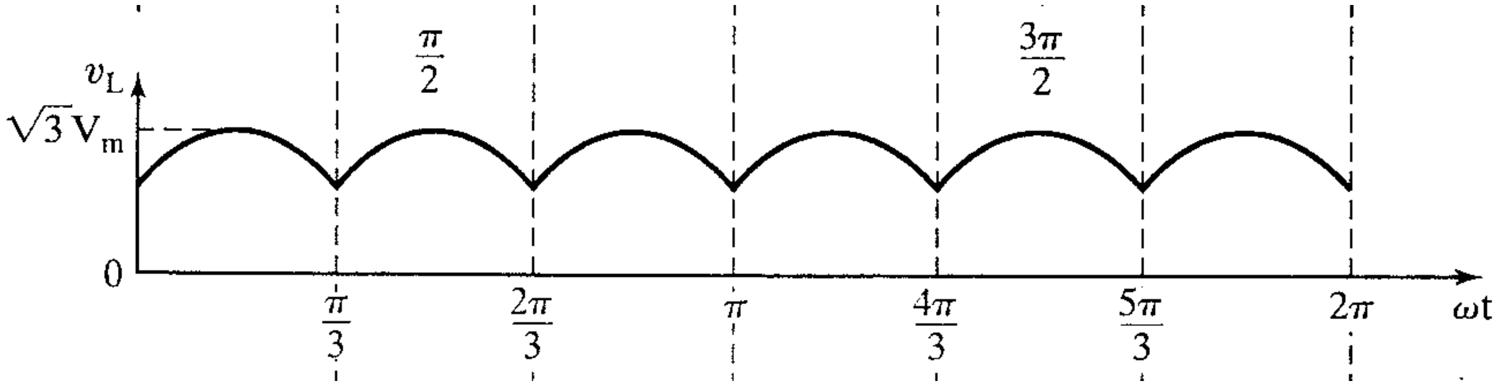
The PIV= $\sqrt{3} \ \ V_m$=650.54V

Three-Phase Bridge Rectifier

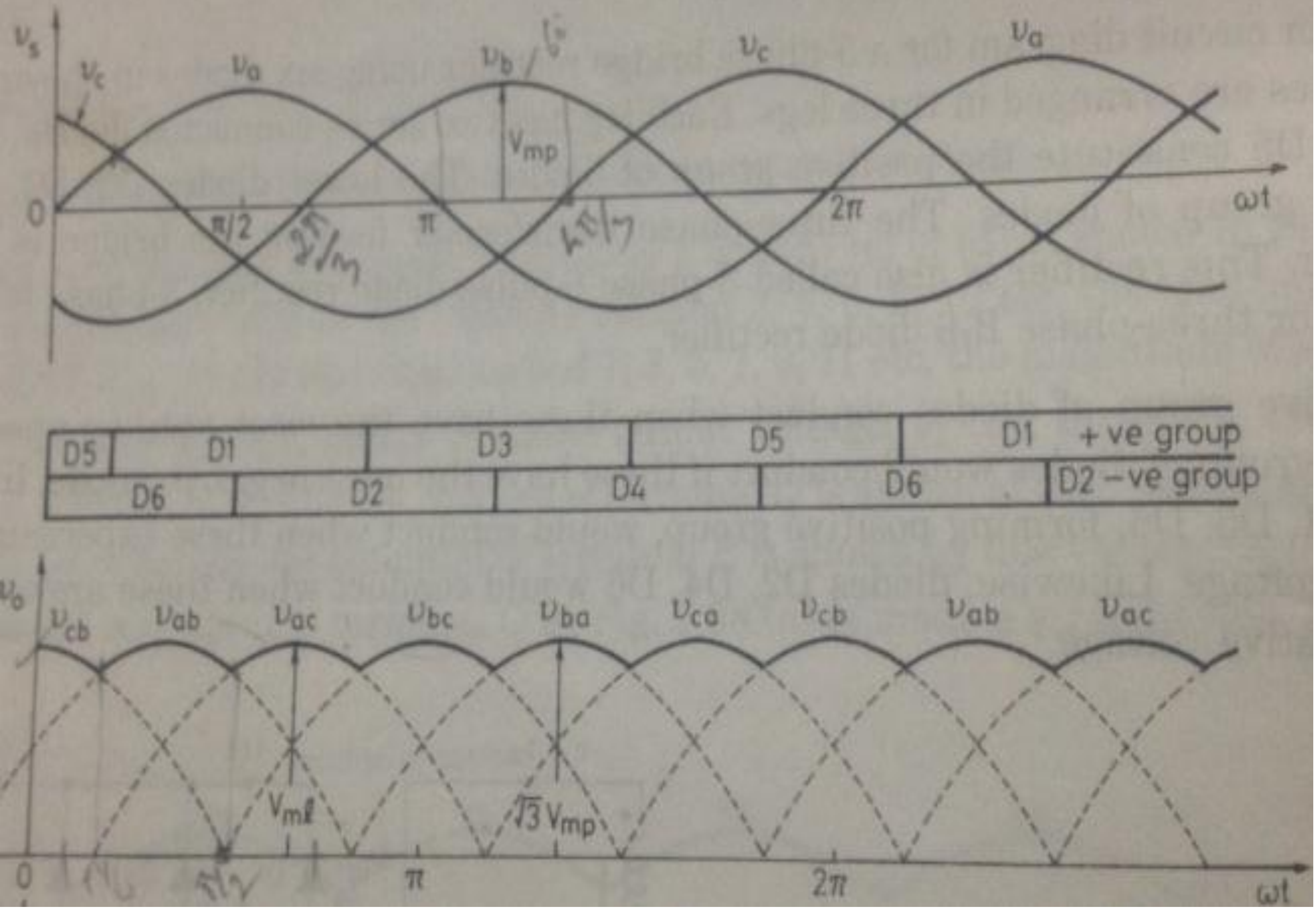




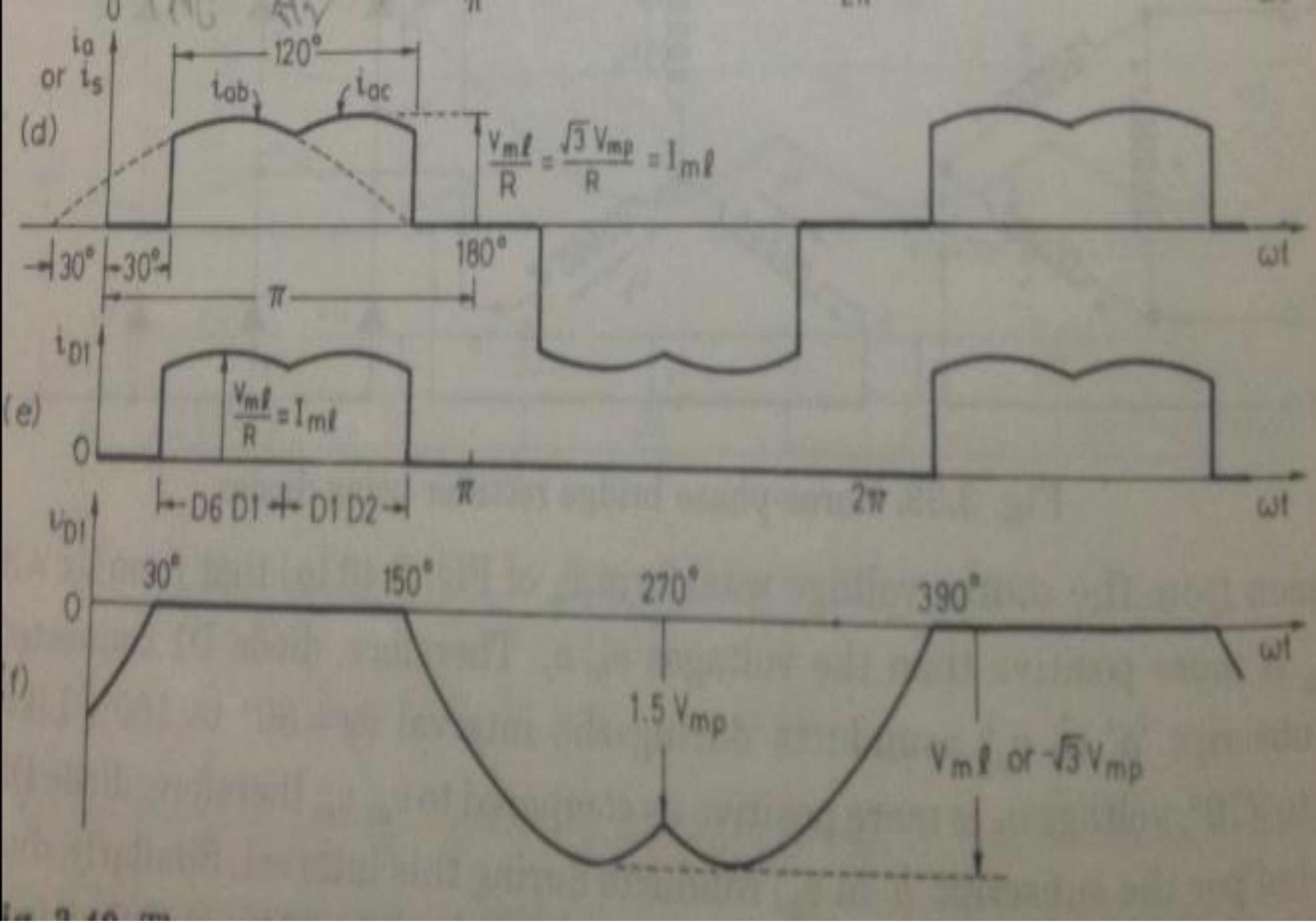
Phase 1
Phase 2
Phase3
1.0
0.5
0
-0.5
-1.0
90°
180°
270°
360°
120°
120°



v_L
$\sqrt{3}V_m$
0
$\frac{\pi}{2}$
$\frac{3\pi}{2}$
$\frac{\pi}{3}$
$\frac{2\pi}{3}$
π
$\frac{4\pi}{3}$
$\frac{5\pi}{3}$
2π
ωt



vs
vc
va
vb
vc
va
Vmp
0
π/2
π
2π
ωt
D5
D1
D3
D5
D1
+ve group
D6
D2
D4
D6
D2 –ve group
vo
vcb
vab
vac
vbc
vba
vca
vcb
vab
vac
Vmℓ
√3 Vmp
0
π
2π
ωt



i_a or i_s
120°
i_{ab}
i_{ac}
(d)
$\frac{V_{m\ell}}{R} = \frac{\sqrt{3}V_{mp}}{R} = I_{m\ell}$
30°
30°
180°
π
ωt
i_{D1}
(e)
$\frac{V_{m\ell}}{R} = I_{m\ell}$
0
D6 D1
D1 D2
π
2π
ωt
v_{D1}
30°
150°
270°
390°
0
ωt
(f)
1.5 V_{mp}
$V_{m\ell}$ or $\sqrt{3}V_{mp}$

$$V_o = \frac{1}{\frac{\pi}{3}} \int_{\frac{\pi}{3}}^{\frac{2\pi}{3}} V_{m_{line}} sin(\omega t) d(\omega t) \qquad = \frac{3}{\pi} V_{line} = 0.955 V_{m_{line}}$$

where,

$$V_{m_{phase}} = \sqrt{2} V_{phase}$$
$$and$$
$$V_{m_{line}} = \sqrt{3} V_{m_{phase}} = \sqrt{6} V_{phase}$$

The RMS value of the output voltage is given by

$$V_{o_{rms}} = \left[\frac{1}{\frac{\pi}{3}} \int_{\frac{\pi}{3}}^{\frac{2\pi}{3}} (V_{m_{line}} sin(\omega t))^2 d(\omega t) \right]^{\frac{1}{2}}$$

$$= 0.9588 V_{m_{line}}$$

Ripple voltage,

$$V_r = \sqrt{V_{o_{rms}}^2 - V_o^2}$$
$$= \sqrt{0.9588^2 - 0.955^2} V_{m_{line}}$$
$$= 0.0853 V_{m_{line}}$$

DC output power,

$$P_o = V_o I_o = \frac{3}{\pi} V_{m_{line}} \frac{3}{\pi} I_{m_{line}}$$
$$= 0.912 V_{m_{line}} I_{m_{line}}$$

AC input power,

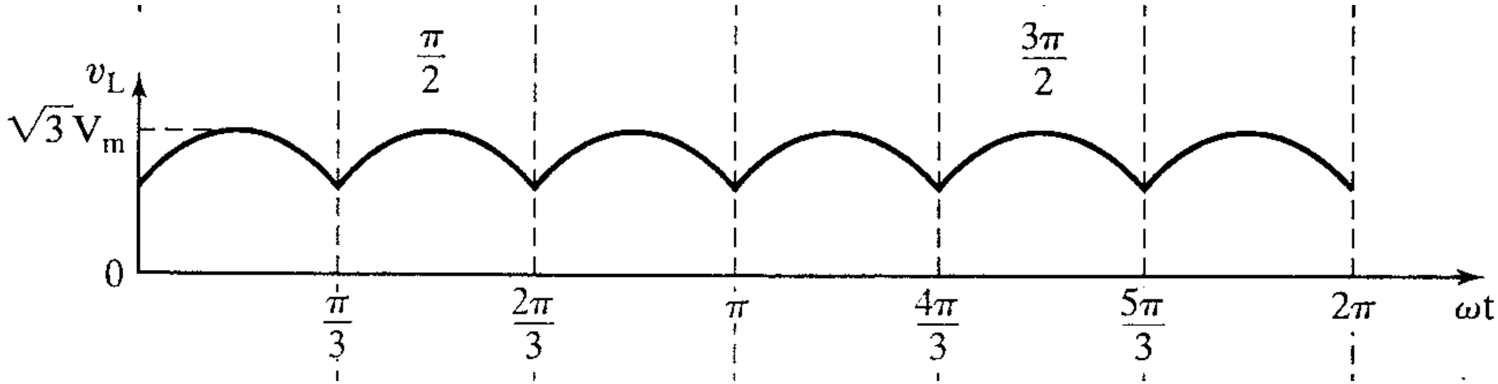
$$P_i = V_{or} I_{or} = (0.9588)^2 V_{m_{line}} I_{m_{line}}$$
$$= 0.9193 V_{m_{phase}} I_{m_{phase}}$$

Efficiency,

$$\eta = \frac{P_o}{P_i} = \frac{0.912 V_{m_{phase}} I_{m_{phase}}}{0.9193 V_{m_{phase}} I_{m_{phase}}}$$

$$= 0.992 = 99.2\%$$

Average Output Voltage, V_{dc}



$$V_{dc} = \frac{1}{T}\int_0^T f(t)dt$$

$$V_{dc} = \frac{2}{\frac{2\pi}{6}}\int_0^{\frac{\pi}{6}} \sqrt{3}V_m \cos\omega t d(\omega t)$$

$$V_{dc} = \frac{3\sqrt{3}}{\pi}V_m = 1.654V_m$$

rms Output Voltage

$$V_{rms} = \left[\frac{2}{\frac{2\pi}{6}} \int_0^{\frac{\pi}{6}} 3V_m^2 \cos^2 \omega t d(\omega t) \right]^{\frac{1}{2}}$$

$$V_{rms} = \left(\frac{3}{2} + \frac{9\sqrt{3}}{4\pi} \right)^{\frac{1}{2}} V_m$$

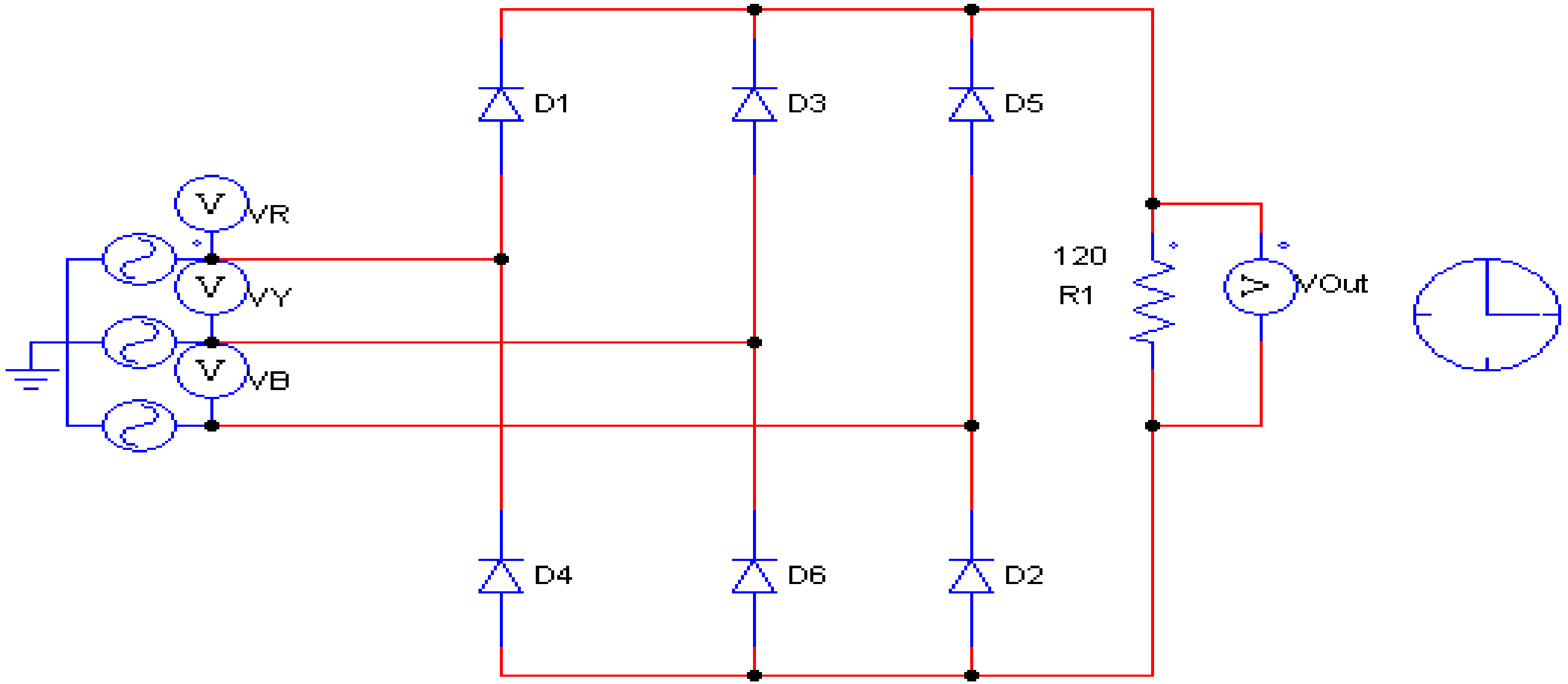
$$\boxed{V_{rms} = 1.6554 V_m}$$

Diode Currents

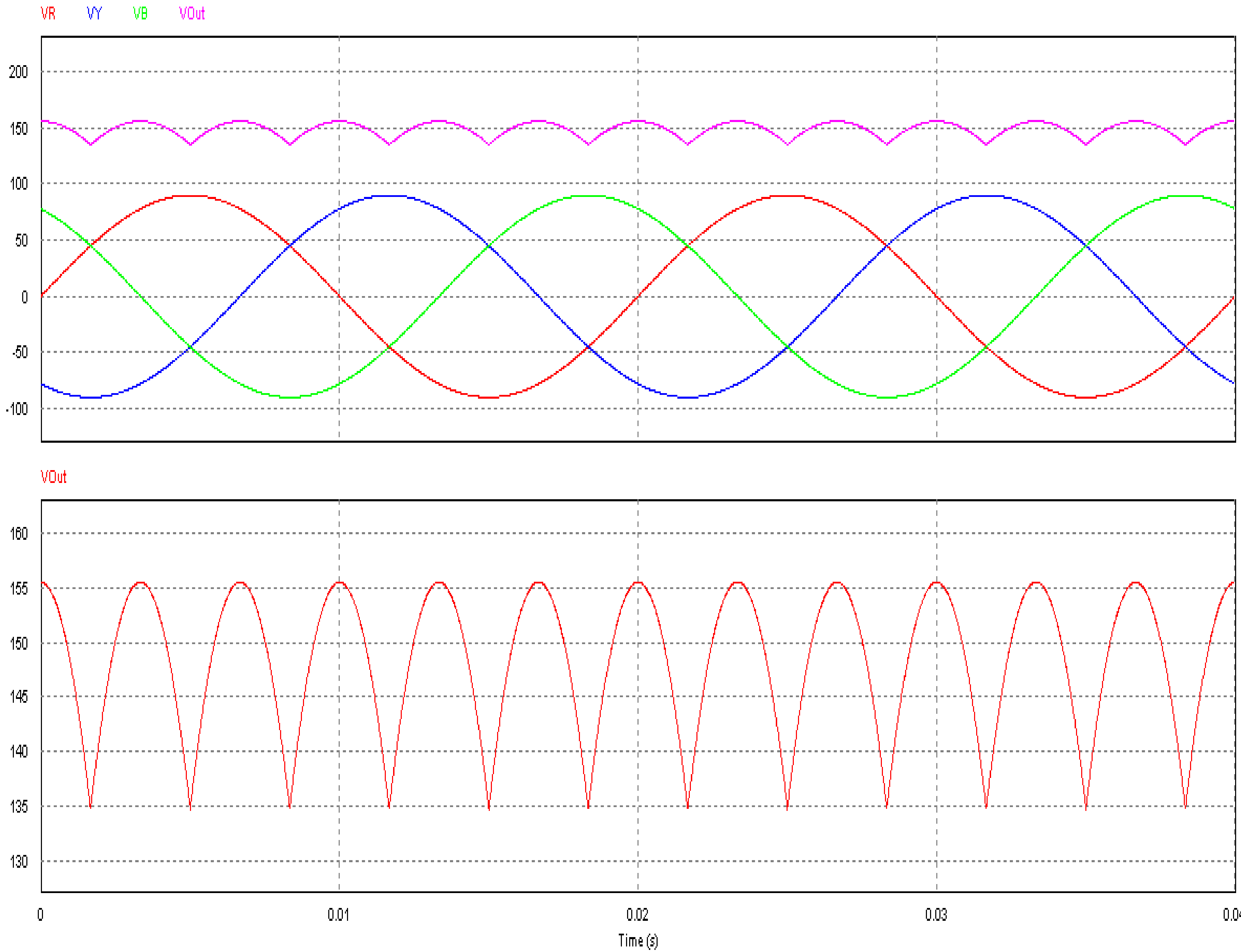
$$I_m = \frac{\sqrt{3}V_m}{R} = peak$$

$$I_r = \left[\frac{4}{2\pi} \int_0^{\frac{\pi}{6}} I_m^2 \cos^2 \omega t d(\omega t) \right]^{\frac{1}{2}}$$

$$\boxed{I_r = 0.5518 I_m}$$

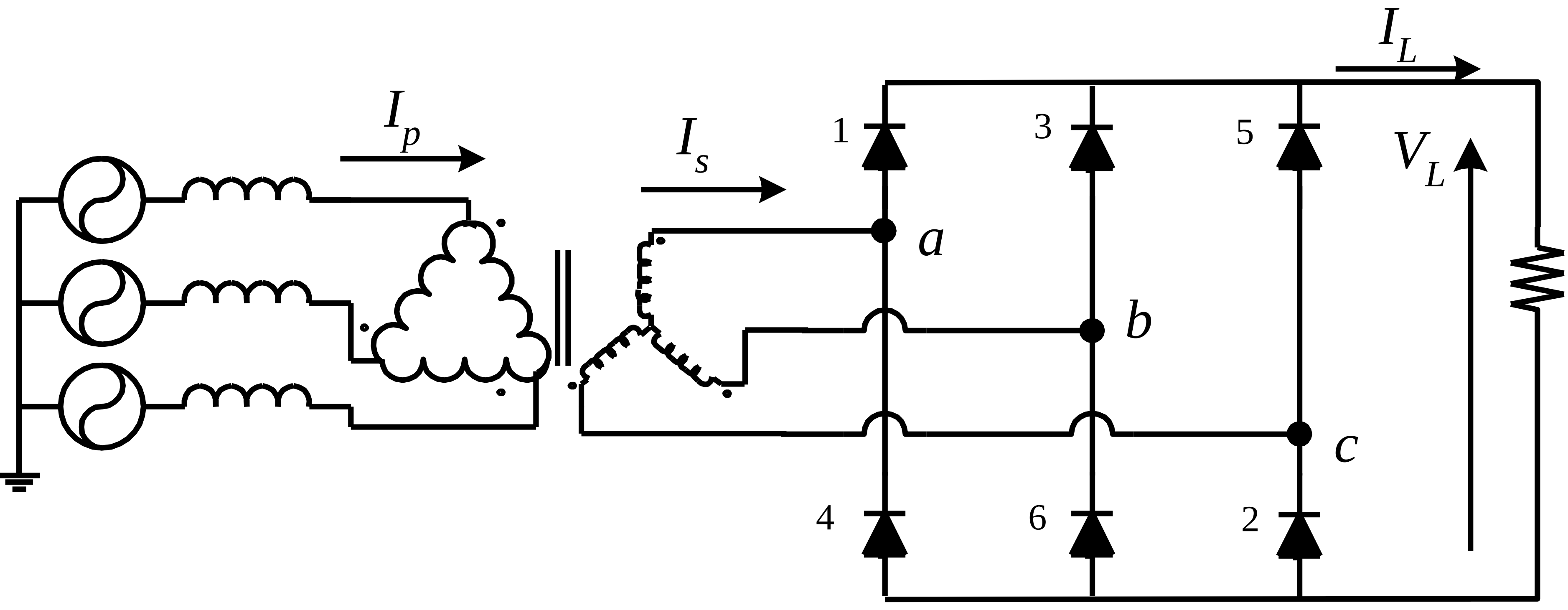


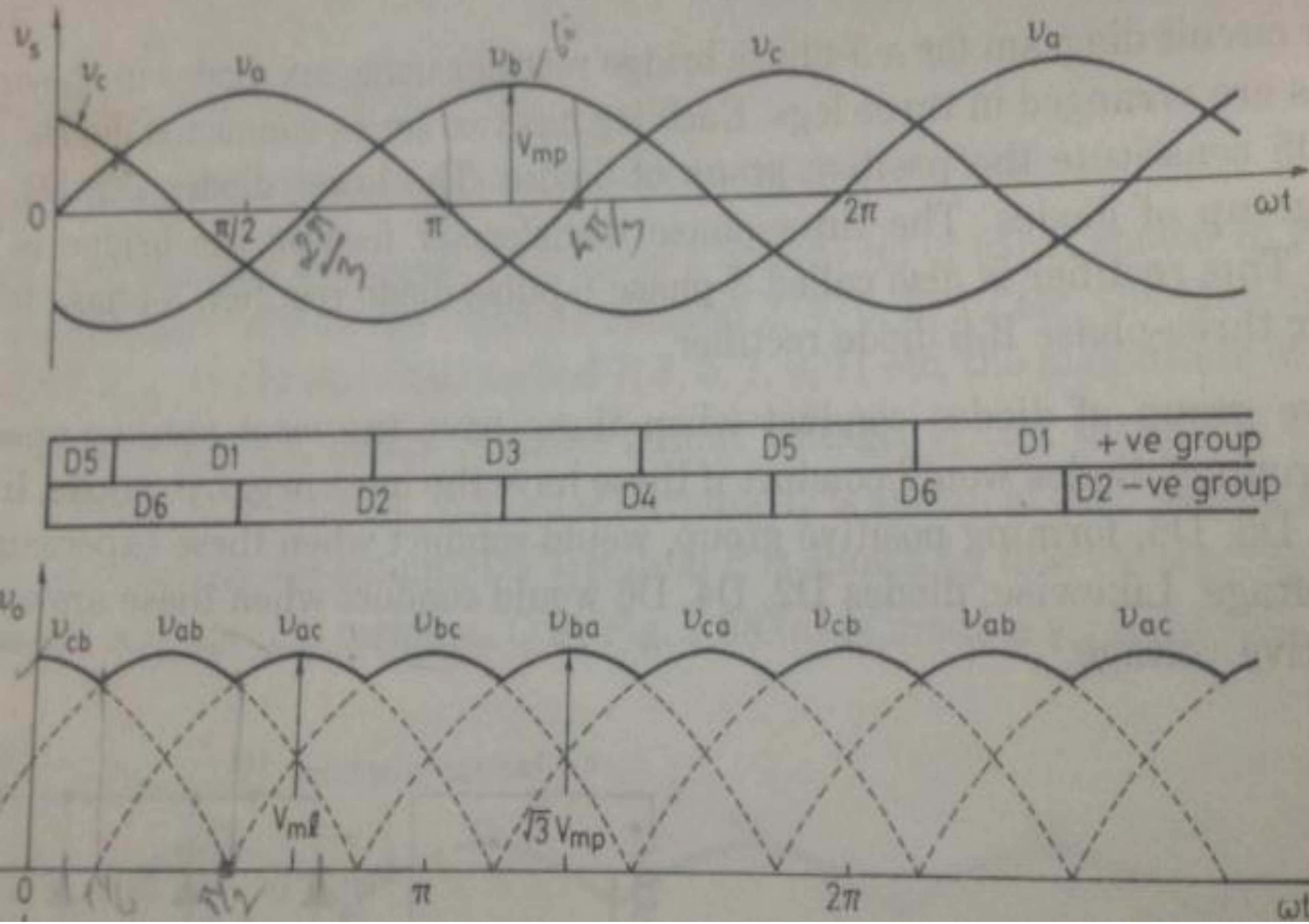
D1
D3
D5
VR
VY
VB
120
R1
VOut
D4
D6
D2



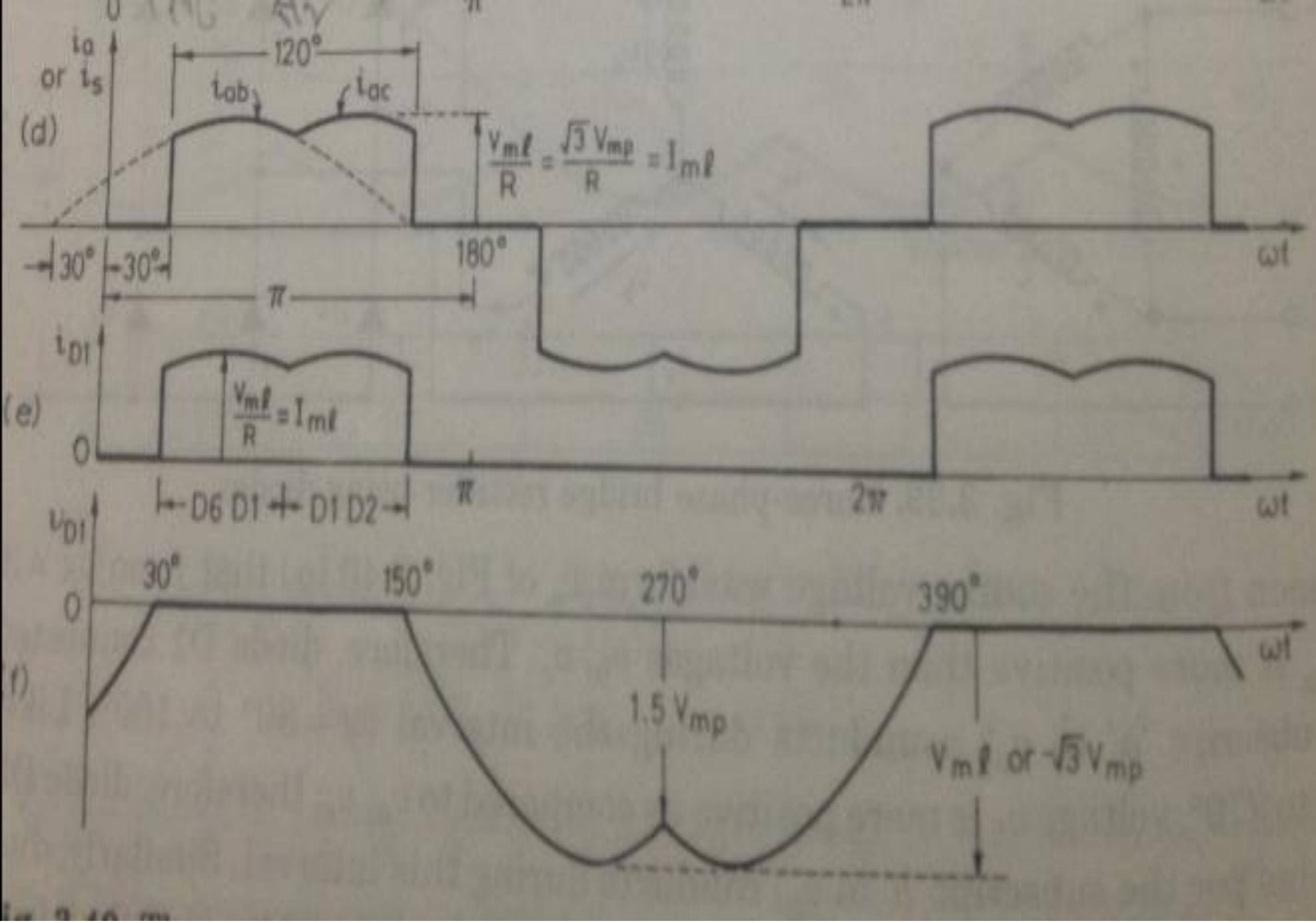
VR
VY
VB
VOut
200
150
100
50
0
-50
-100
VOut
160
155
150
145
140
135
130
0
0.01
0.02
0.03
0.04
Time (s)

Three-Phase Full Wave Rectifier With Resistive Load

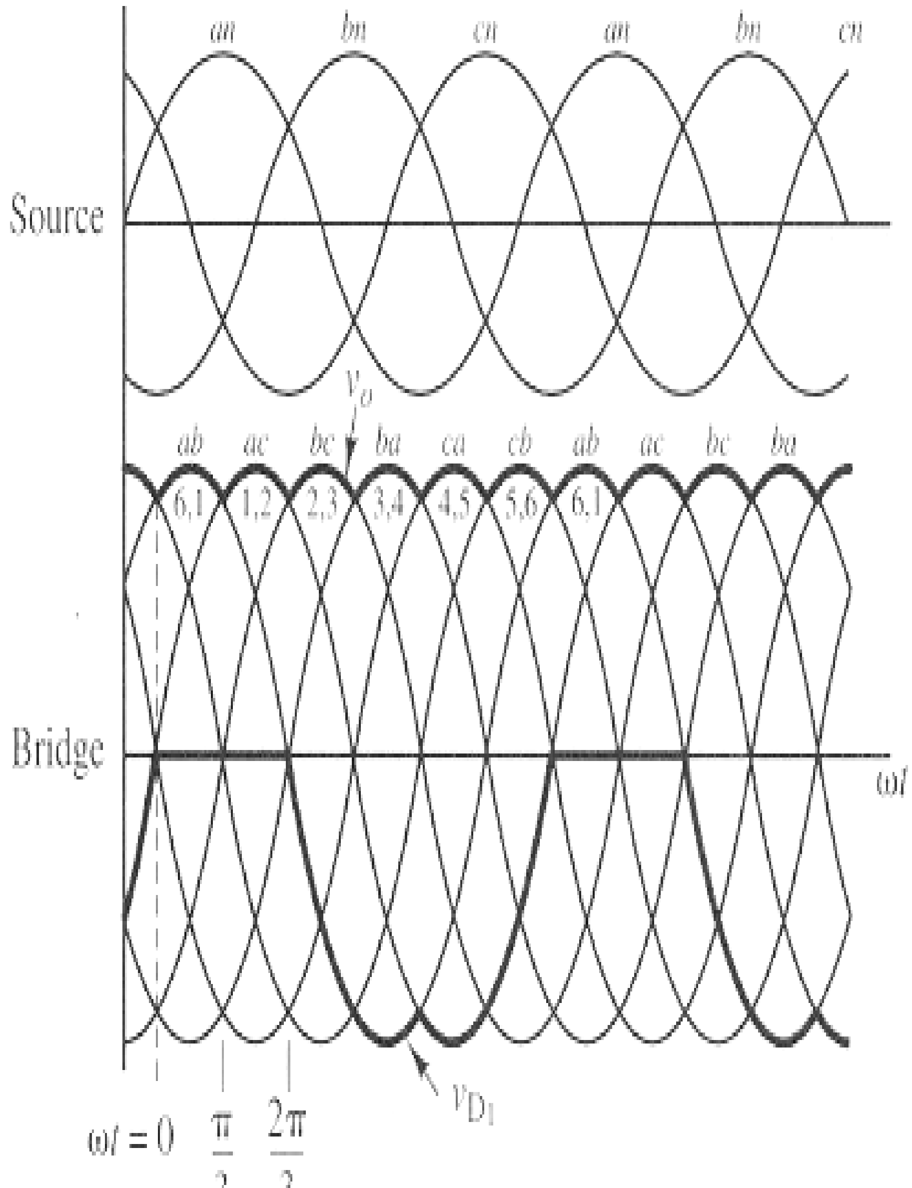


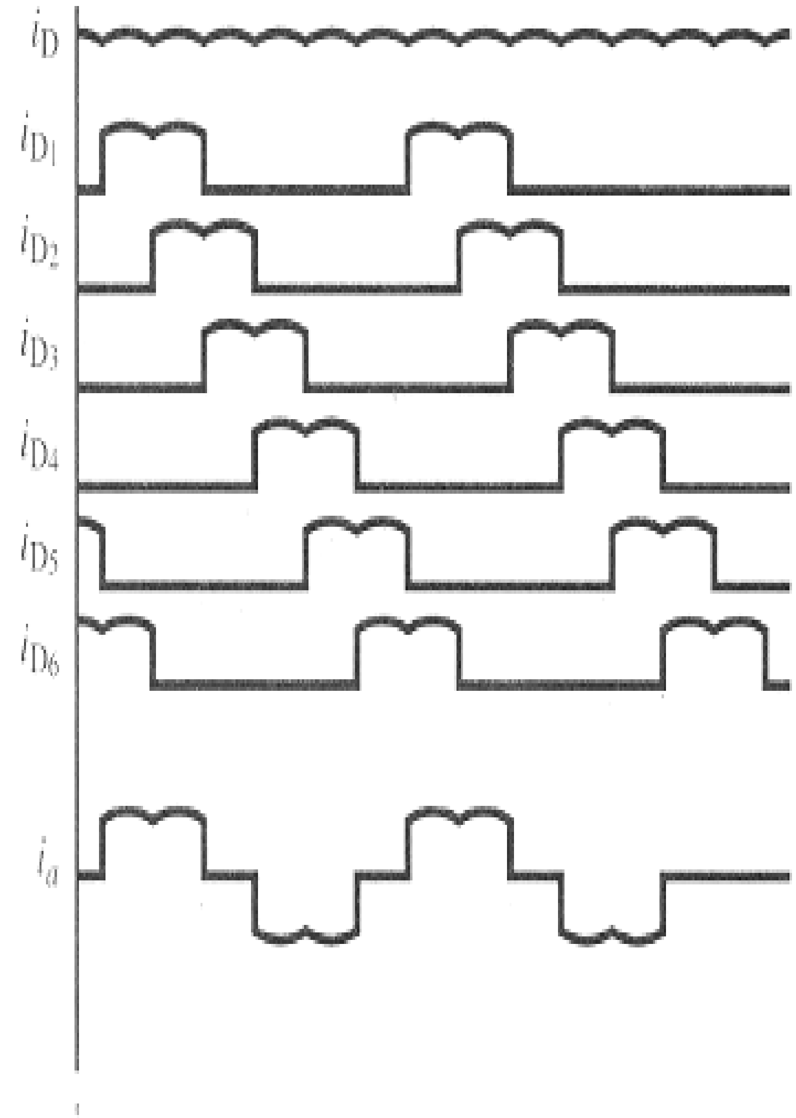


v_s
v_c
v_a
v_b
v_c
v_a
V_{mp}
0
π/2
π
2π
ωt
D5
D1
D3
D5
D1
+ve group
D6
D2
D4
D6
D2 −ve group
v_o
v_{cb}
v_{ab}
v_{ac}
v_{bc}
v_{ba}
v_{ca}
v_{cb}
v_{ab}
v_{ac}
$V_{m\ell}$
$\sqrt{3}\,V_{mp}$
0
π
2π
ωt



i_a or i_s
120°
i_{ab}
i_{ac}
(d)
$\frac{V_{m\ell}}{R} = \frac{\sqrt{3}\,V_{mp}}{R} = I_{m\ell}$
30°
30°
180°
π
ωt
i_{D1}
(e)
$\frac{V_{m\ell}}{R} = I_{m\ell}$
0
D6 D1
D1 D2
π
2π
ωt
v_{D1}
30°
150°
270°
390°
0
ωt
(f)
1.5 V_{mp}
$V_{m\ell}$ or $\sqrt{3}\,V_{mp}$


an
bn
cn
an
bn
cn
Source
v_o
ab
ac
bc
ba
ca
cb
ab
ac
bc
ba
6,1
1,2
2,3
3,4
4,5
5,6
6,1
Bridge
ωt
v_{D_1}
ωt = 0
π/3
2π/3
(b)


i_D
i_{D_1}
i_{D_2}
i_{D_3}
i_{D_4}
i_{D_5}
i_{D_6}
i_a
(c)