Industrial Electronics and control of Drives

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Inverters

Inverter

- A device that converts DC power in to AC power at desired output voltage and frequency.
- These are used for adjustable speed ac drives, induction heating, aircraft power supplies, UPS, HVDC transmission lines etc.

Classification

- **According to output**:
  - Single phase Inverter
  - Three phase Inverter

- **According to Input Source**:
  - Voltage Source Inverter
  - Current Source Inverter

Classification

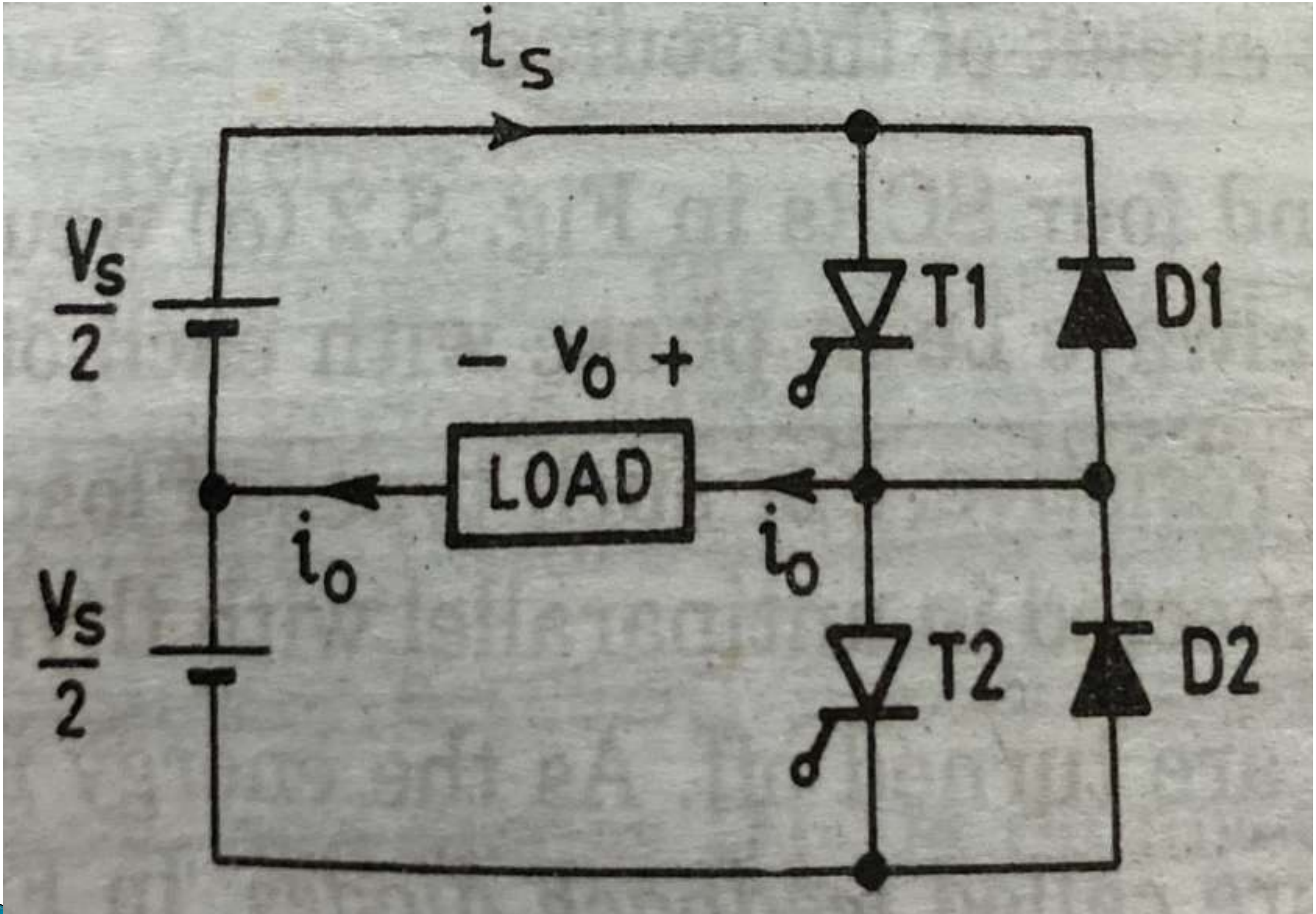
- **According to Method of Commutation**:
  - Line Commutated Inverter
  - Forced Commutated Inverter
- **According to Connections of Commutating Components**:
  - Bridge Inverter
  - Series Inverter
  - Parallel Inverter

- **Voltage Source Inverters:** In these, DC source has small or negligible impedance.

- **Current Source Inverters:** In these, DC source has high impedance.

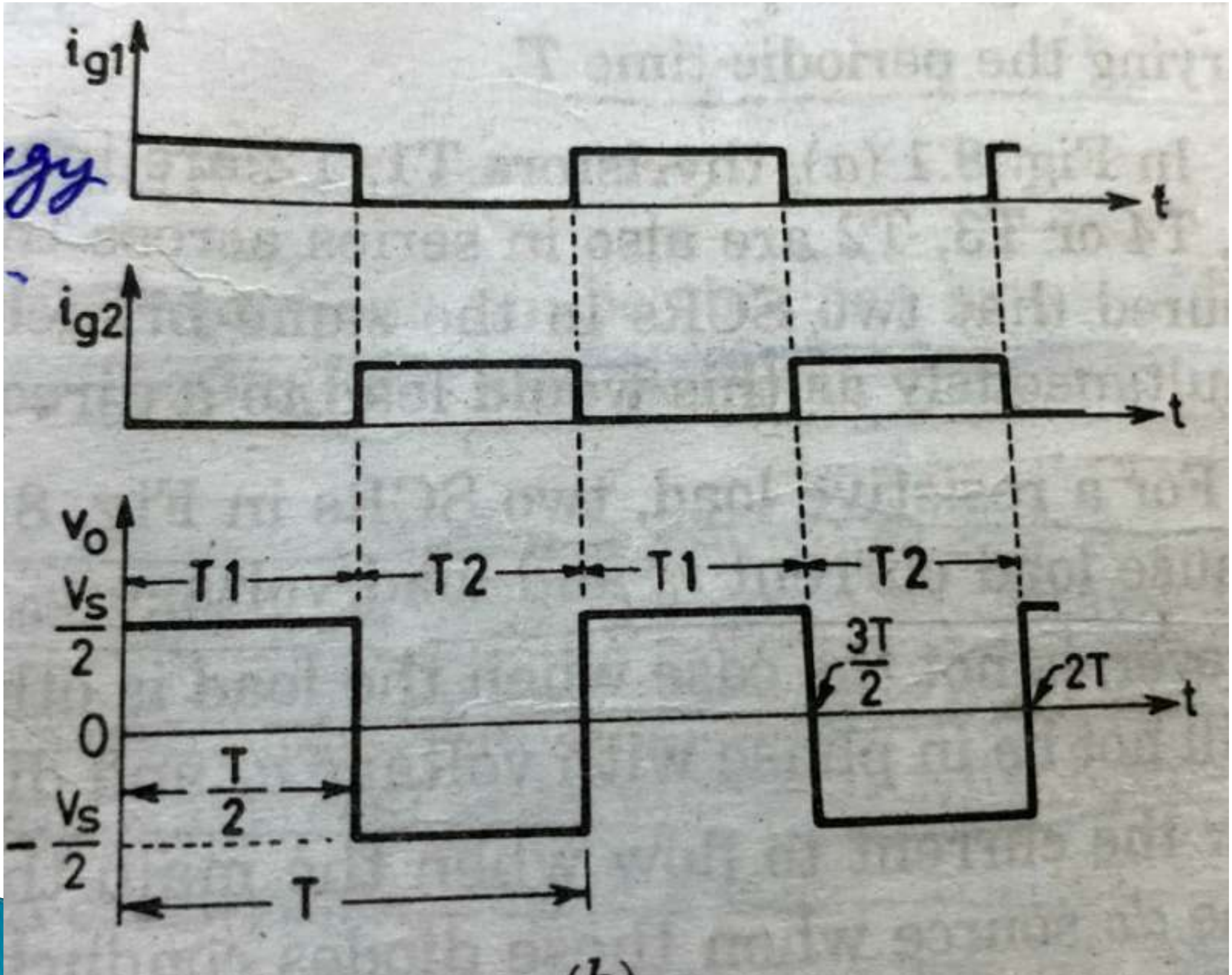
Bridge Inverters

Half Bridge Inverters



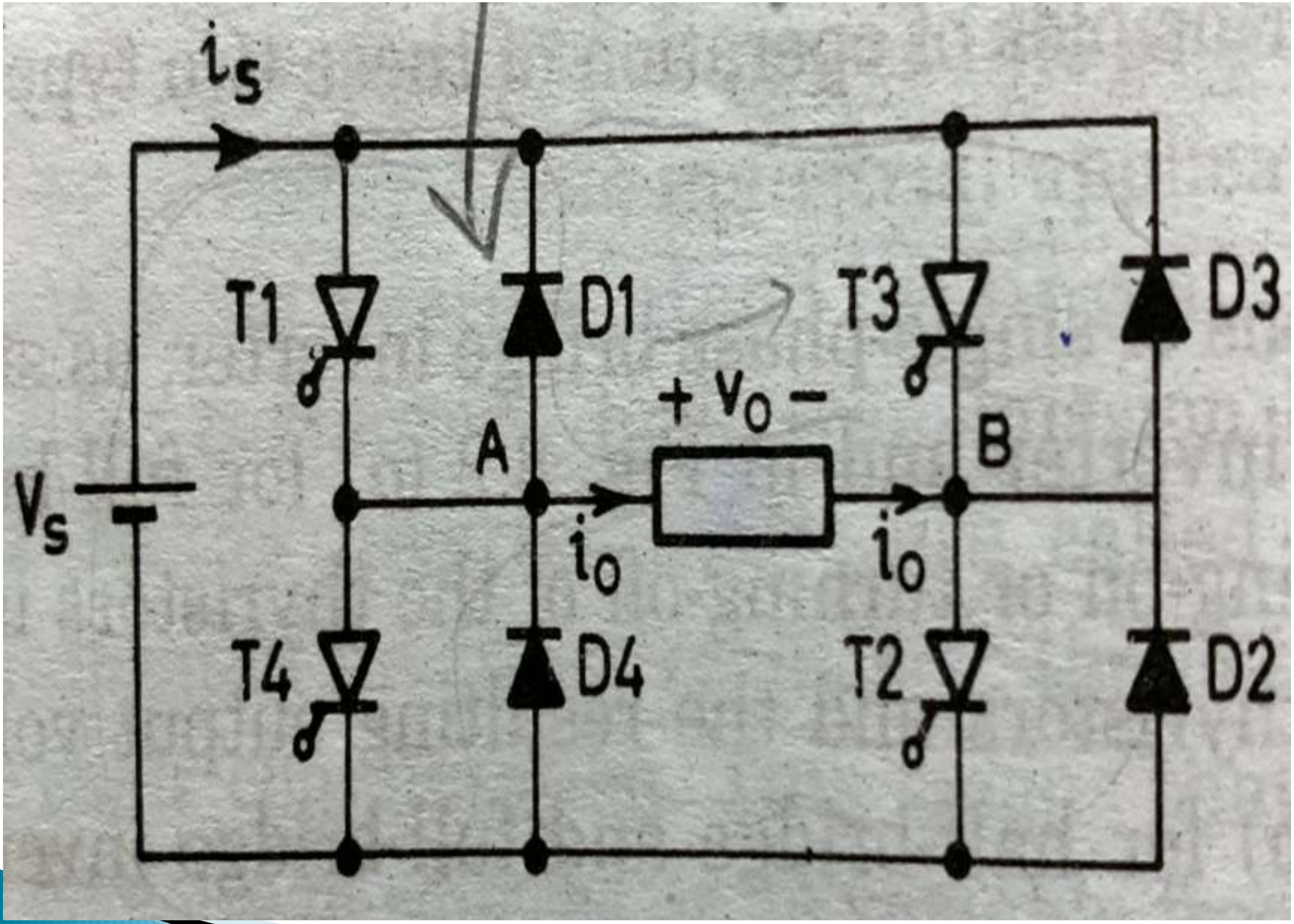
i_s
$\frac{V_s}{2}$
T1
D1
$- \ v_0 \ +$
LOAD
i_0
i_0
$\frac{V_s}{2}$
T2
D2

- D1 and D2 are **Feedback diodes**, as they feed the stored energy back to source.
- Main drawback is that 3 wire DC supply is required.

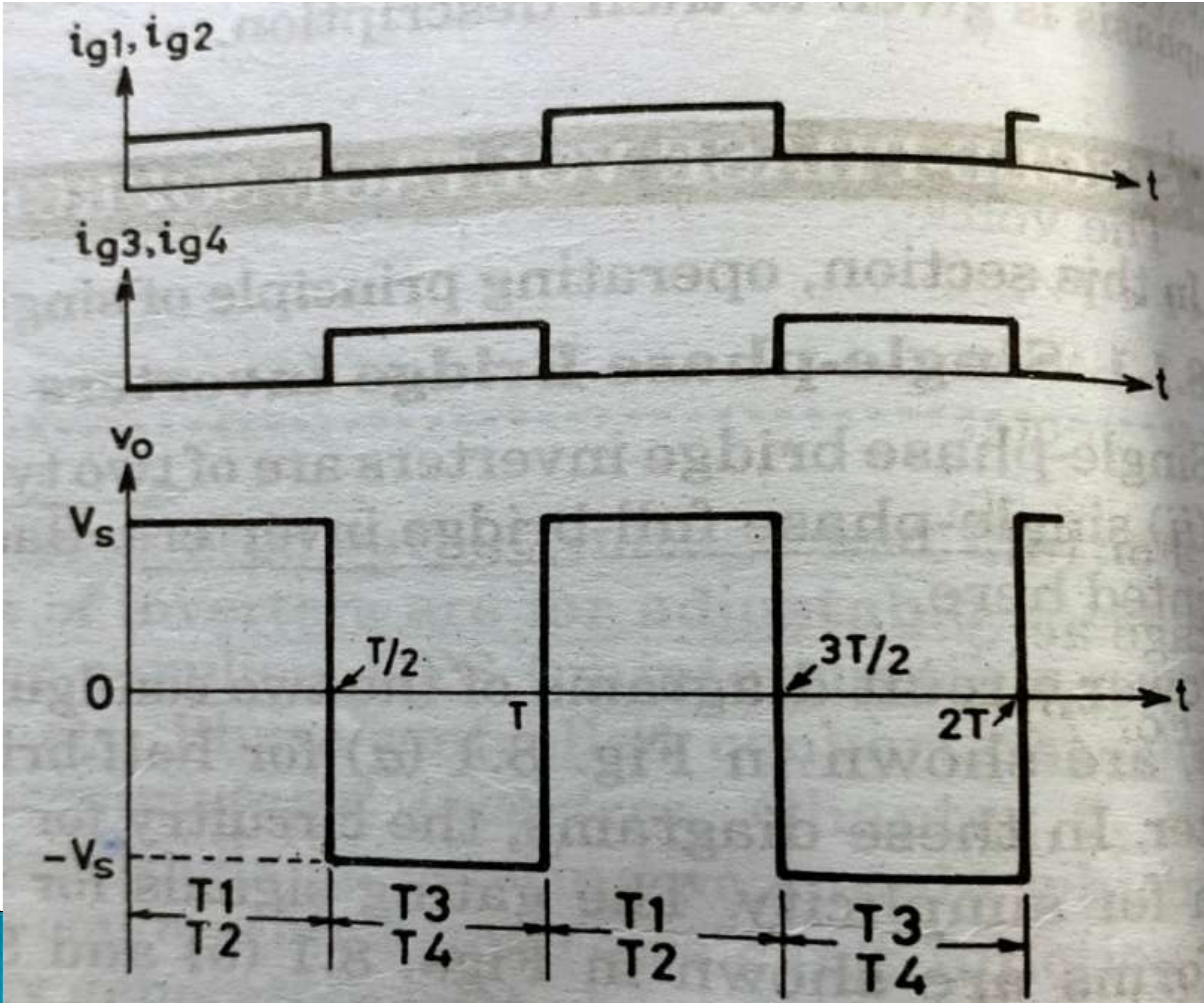


i_{g1}
t
i_{g2}
t
v_o
T1
T2
T1
T2
$\frac{V_S}{2}$
$\frac{3T}{2}$
2T
t
0
$\frac{T}{2}$
$-\frac{V_S}{2}$
T
(b)

Full Bridge Inverters

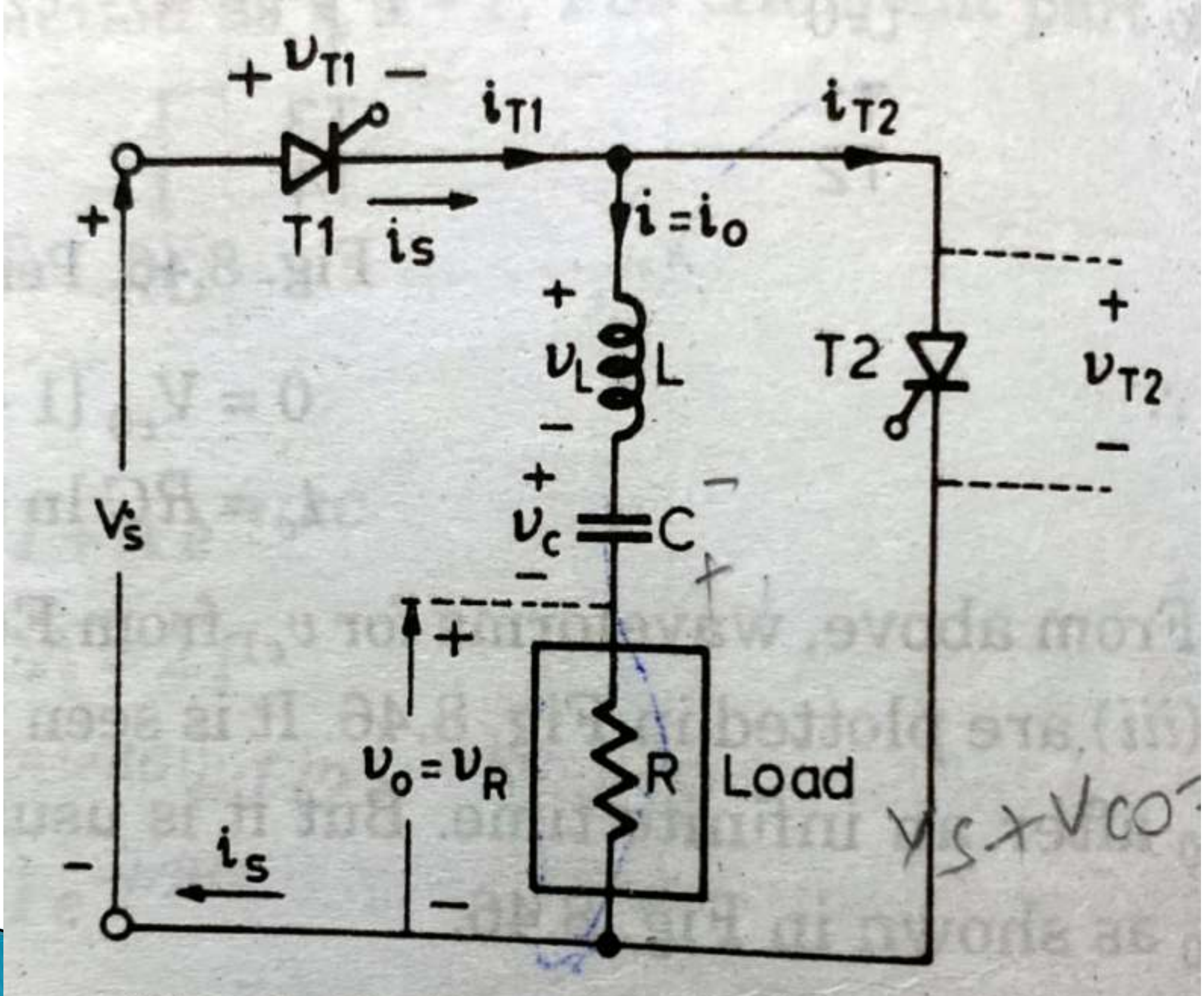


i_s
T1
D1
T3
D3
+ v_o −
A
B
V_s
i_o
i_o
T4
D4
T2
D2



i_{g1}, i_{g2}
t
i_{g3}, i_{g4}
t
v_o
V_s
0
$-V_s$
T/2
T
3T/2
2T
t
T1
T2
T3
T4
T1
T2
T3
T4

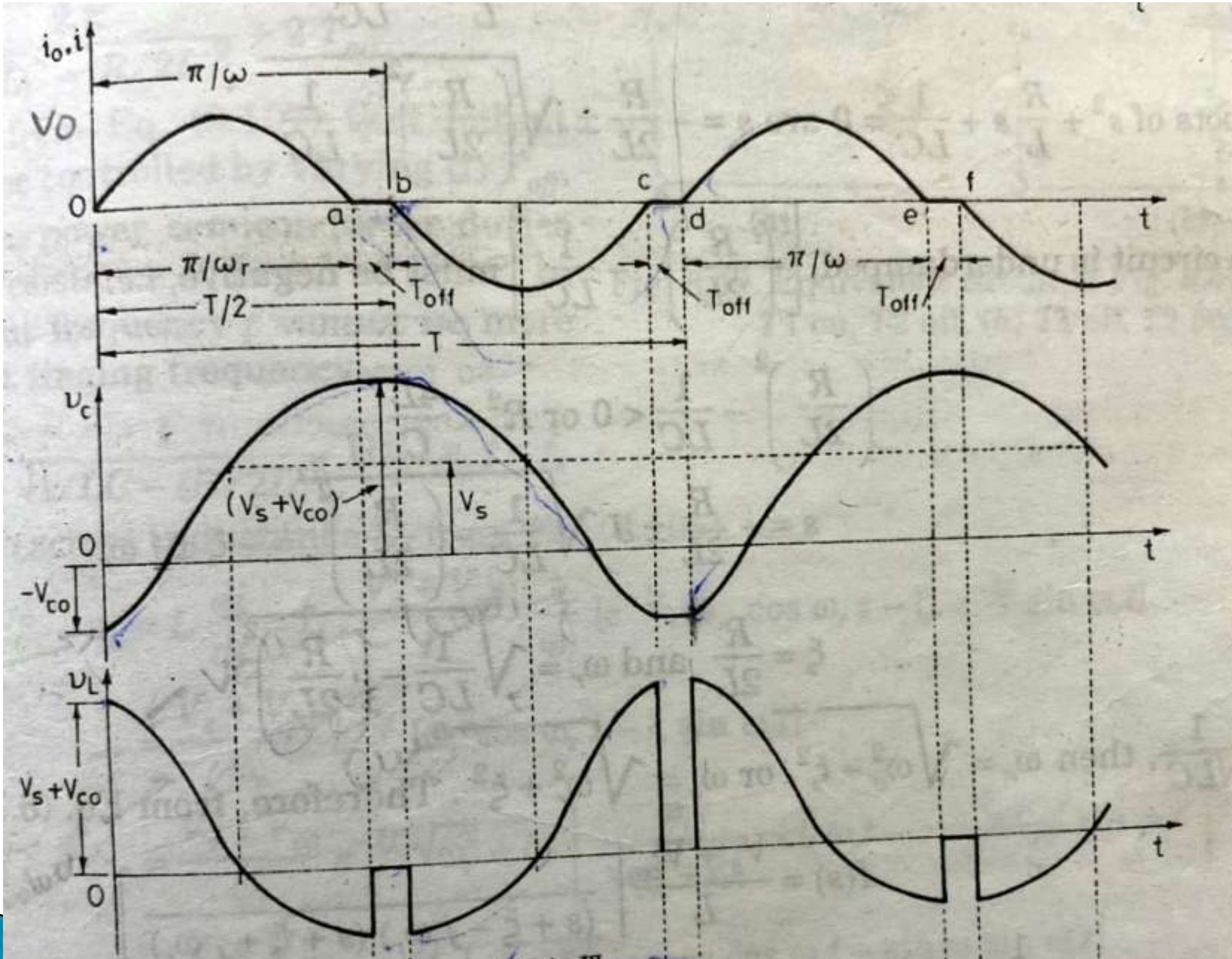
Series Inverter



$+ \; v_{T1} \; -$
i_{T1}
i_{T2}
T1
i_s
$i = i_o$
+
v_L
L
−
+
v_c
C
−
T2
+
v_{T2}
−
V_s
+
−
$v_o = v_R$
R
Load
i_s
+
−
Vs+Vco

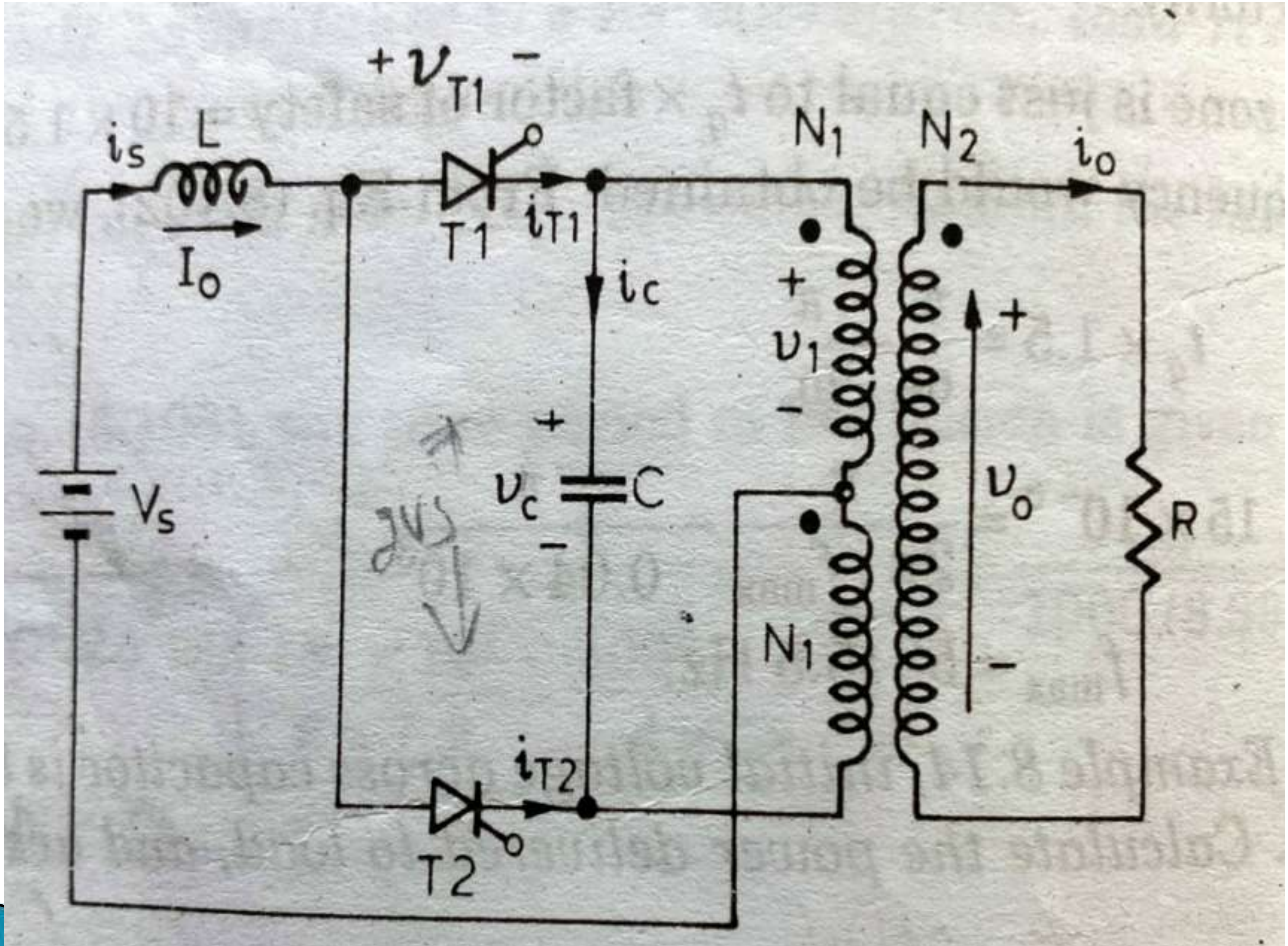
- Inverters in which commutating components are permanently connected in series with the load are called series inverters.
- The value of R, L and is so chosen that the series RLC circuit forms an underdamped circuit.
- On turning on of $T_{1,}$ current I starts building up in RLC circuit.

- As the circuit is underdamped, current decays to zero and tends to reverse.
- SCR T_1 turns off.
- SCR T_2 is turned ON.
- Capacitor begins to discharge and load current is reversed.
- Load current decays to zero, after some time.

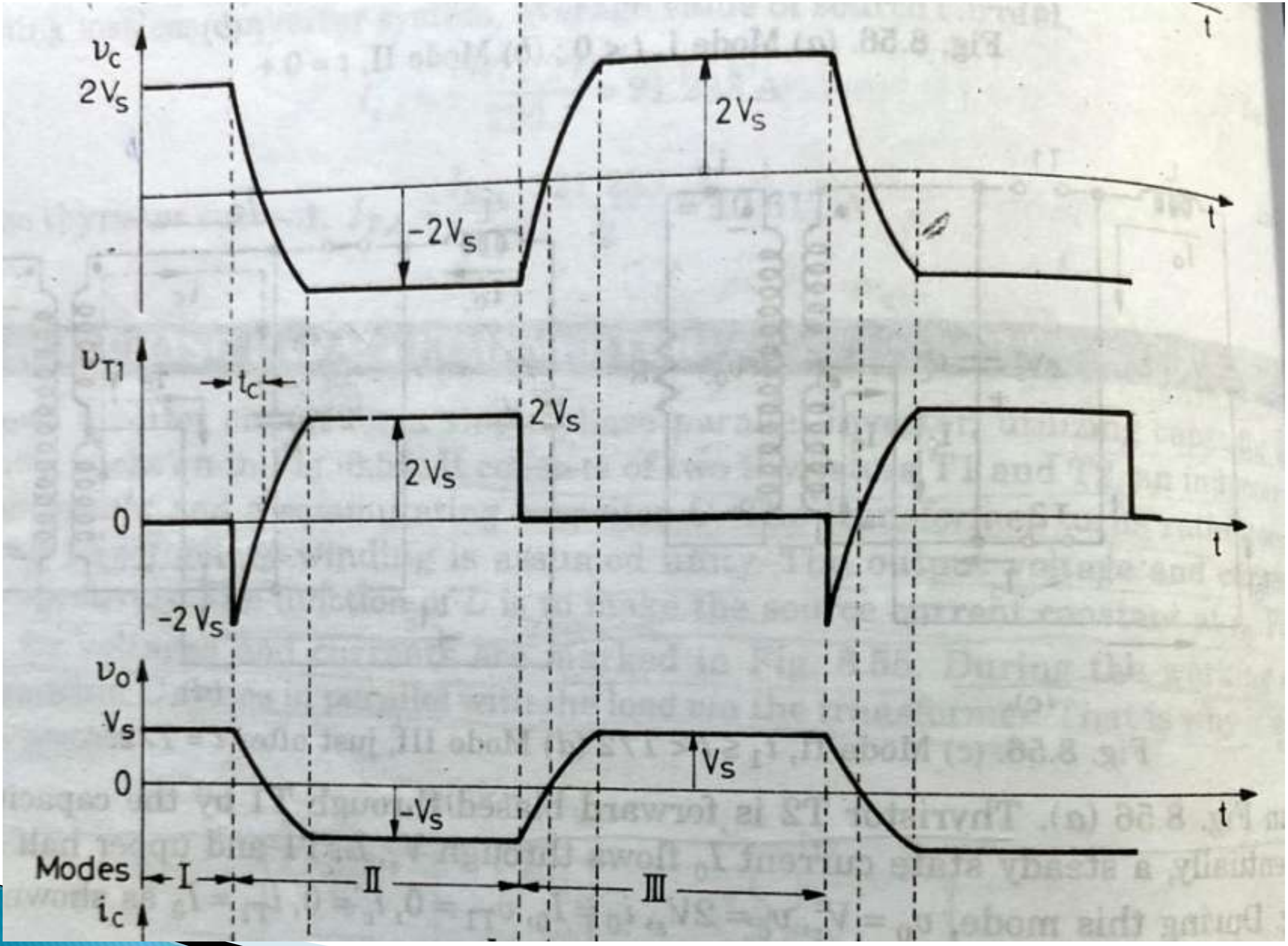


i_o, i
π/ω
V_O
0
a
b
c
d
e
f
t
π/ω_r
T_{off}
$T/2$
T
π/ω
T_{off}
T_{off}
v_c
$(V_s + V_{co})$
V_s
0
$-V_{co}$
t
v_L
$V_s + V_{co}$
0
t

Parallel Inverter

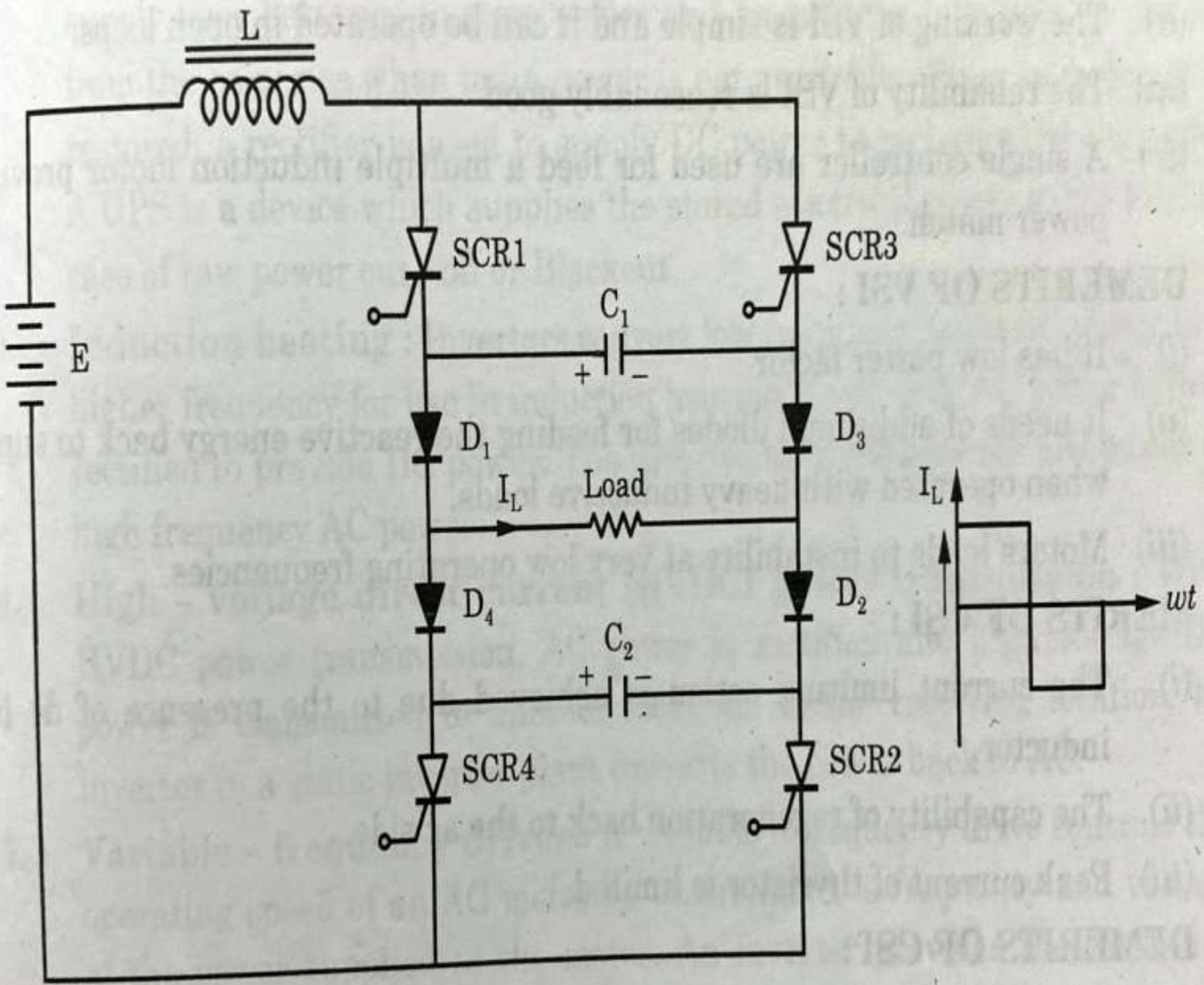


+ v_{T1} −
i_s
L
I_o
T1
i_{T1}
i_c
N1
N2
i_o
+
v_1
−
+
v_c
C
−
V_s
v_o
R
N1
i_{T2}
T2



v_c
$2V_s$
$-2V_s$
$2V_s$
t
v_{T1}
t_c
$2V_s$
$2V_s$
0
$-2V_s$
t
v_o
V_s
0
$-V_s$
V_s
t
Modes
I
II
III
i_c

Current Source Inverter

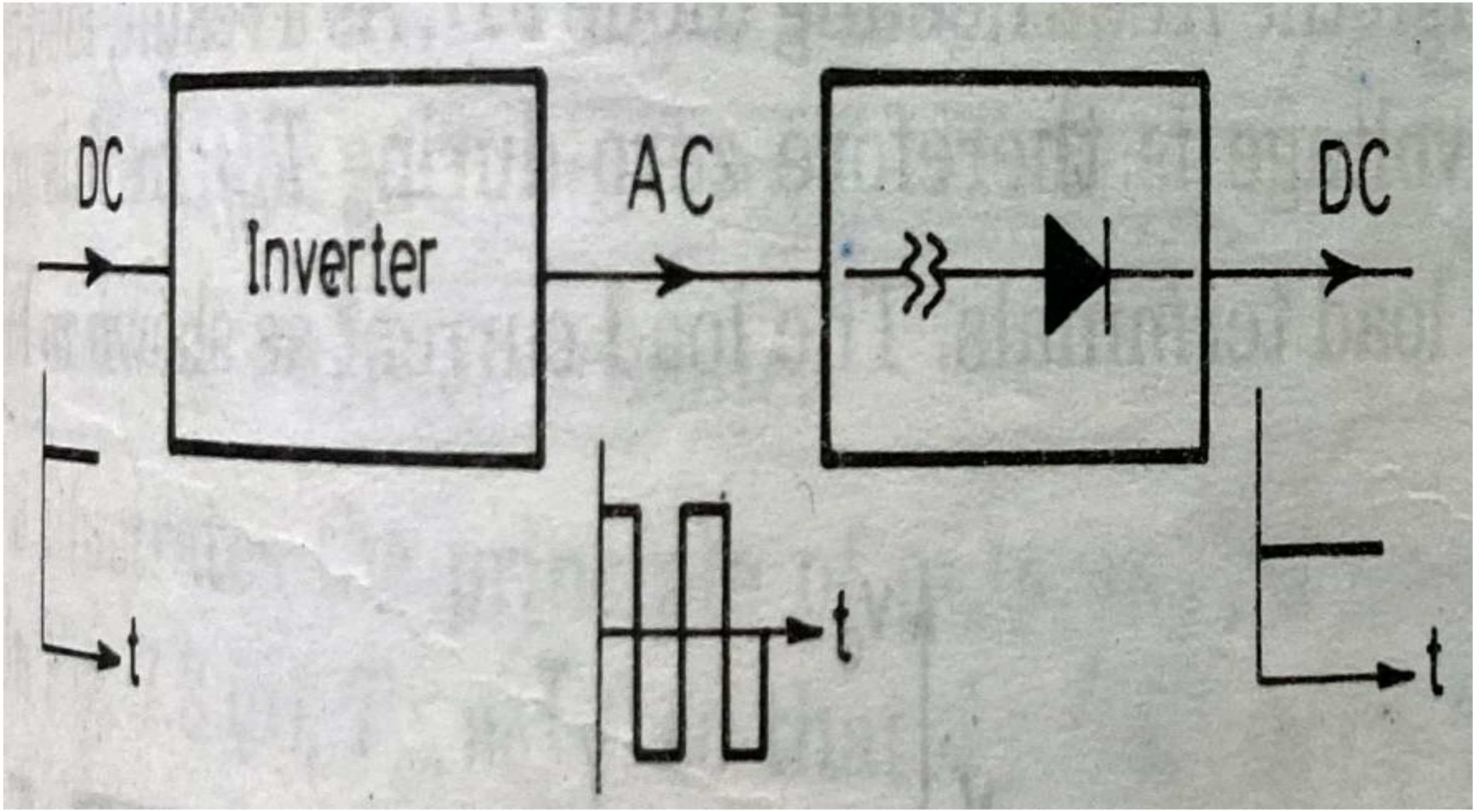


L
SCR1
SCR3
C1
E
+
−
D1
D3
IL
Load
IL
D4
D2
wt
C2
+
−
SCR4
SCR2

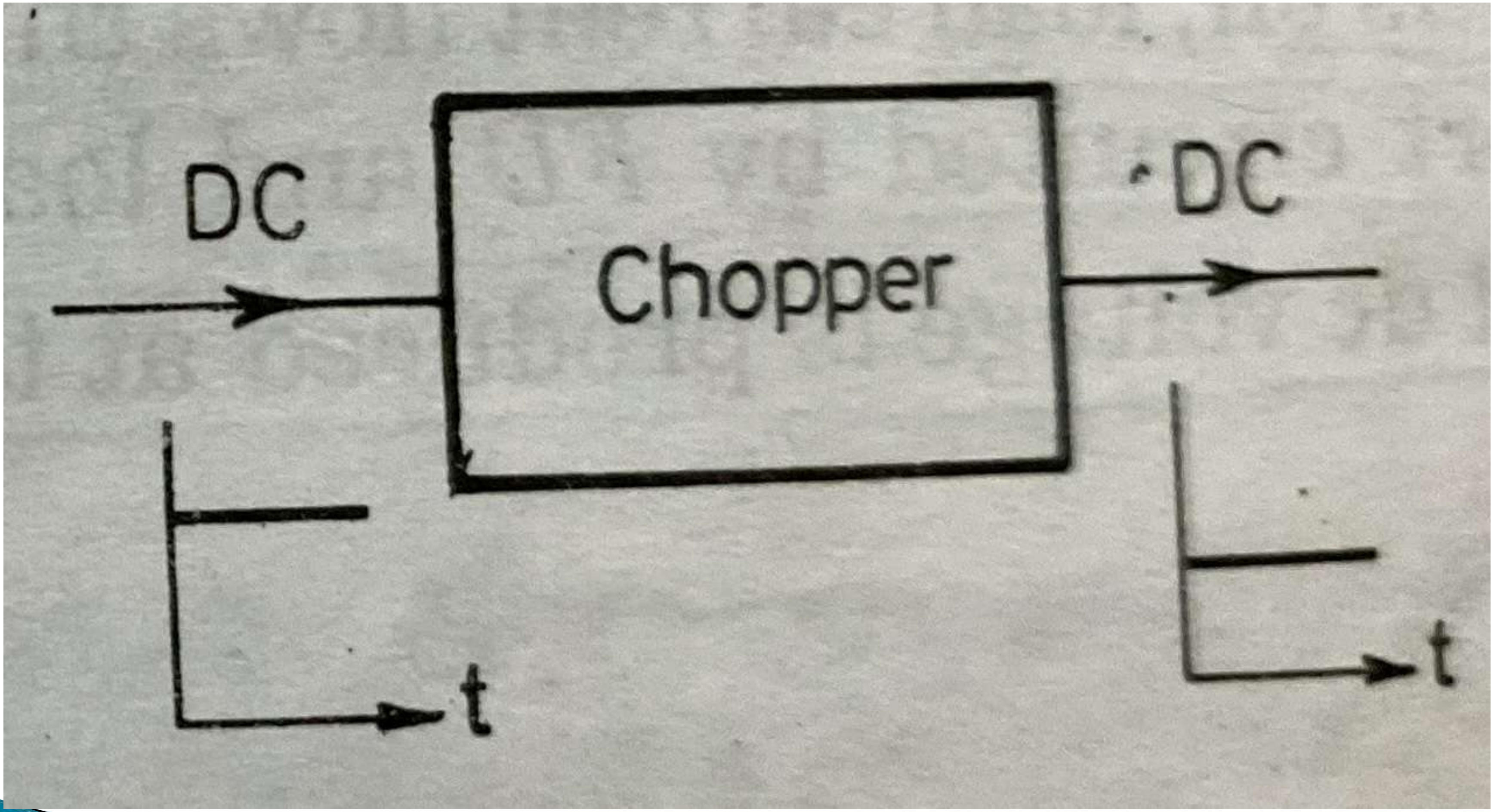
Choppers

Chopper

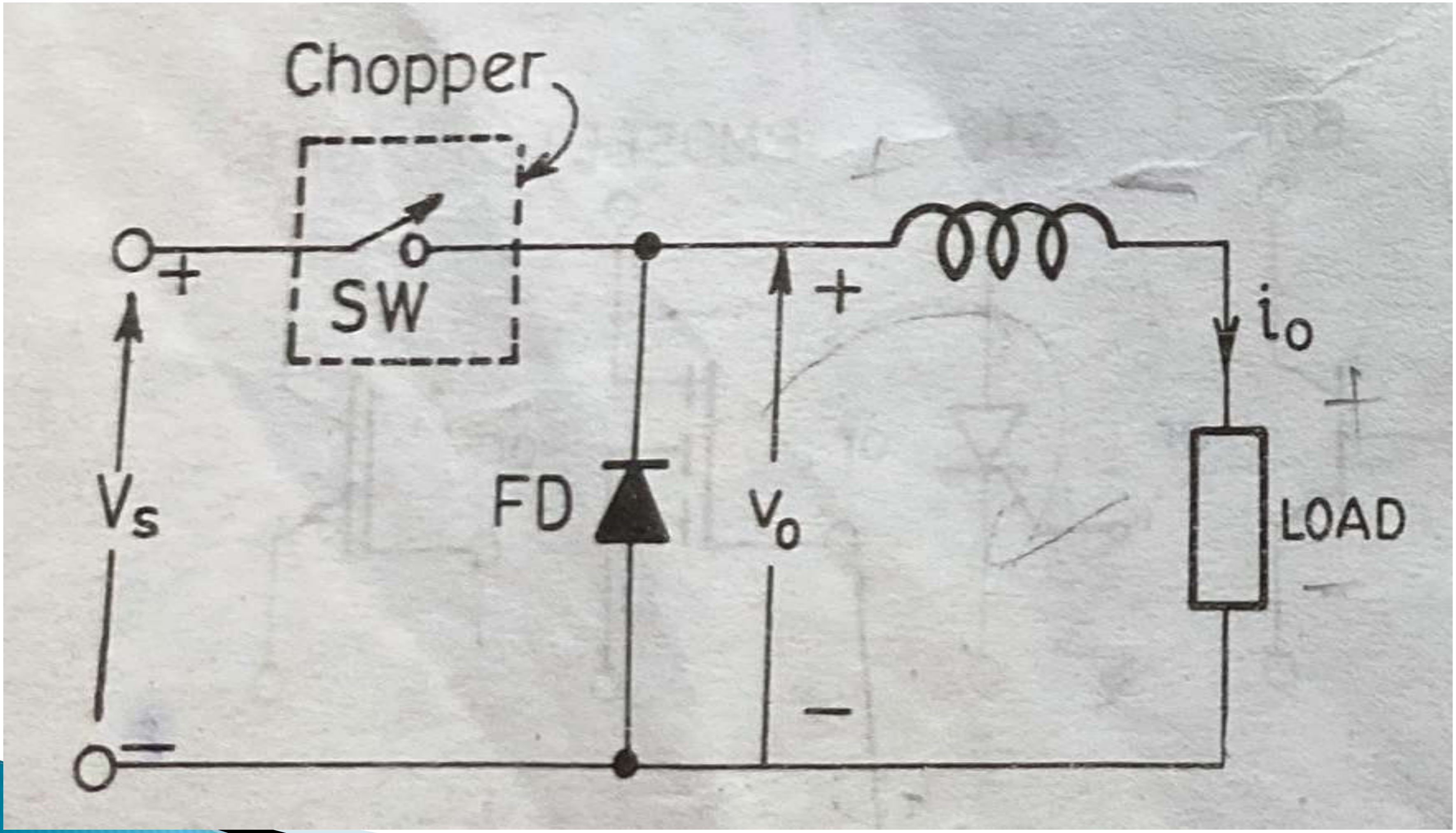
- Chopper is a static device that converts fixed DC input voltage to a variable DC output voltage.
- Chopper may be thought as a DC equivalent of an AC transformer.
- These involve one stage conversion.
- These are more efficient.

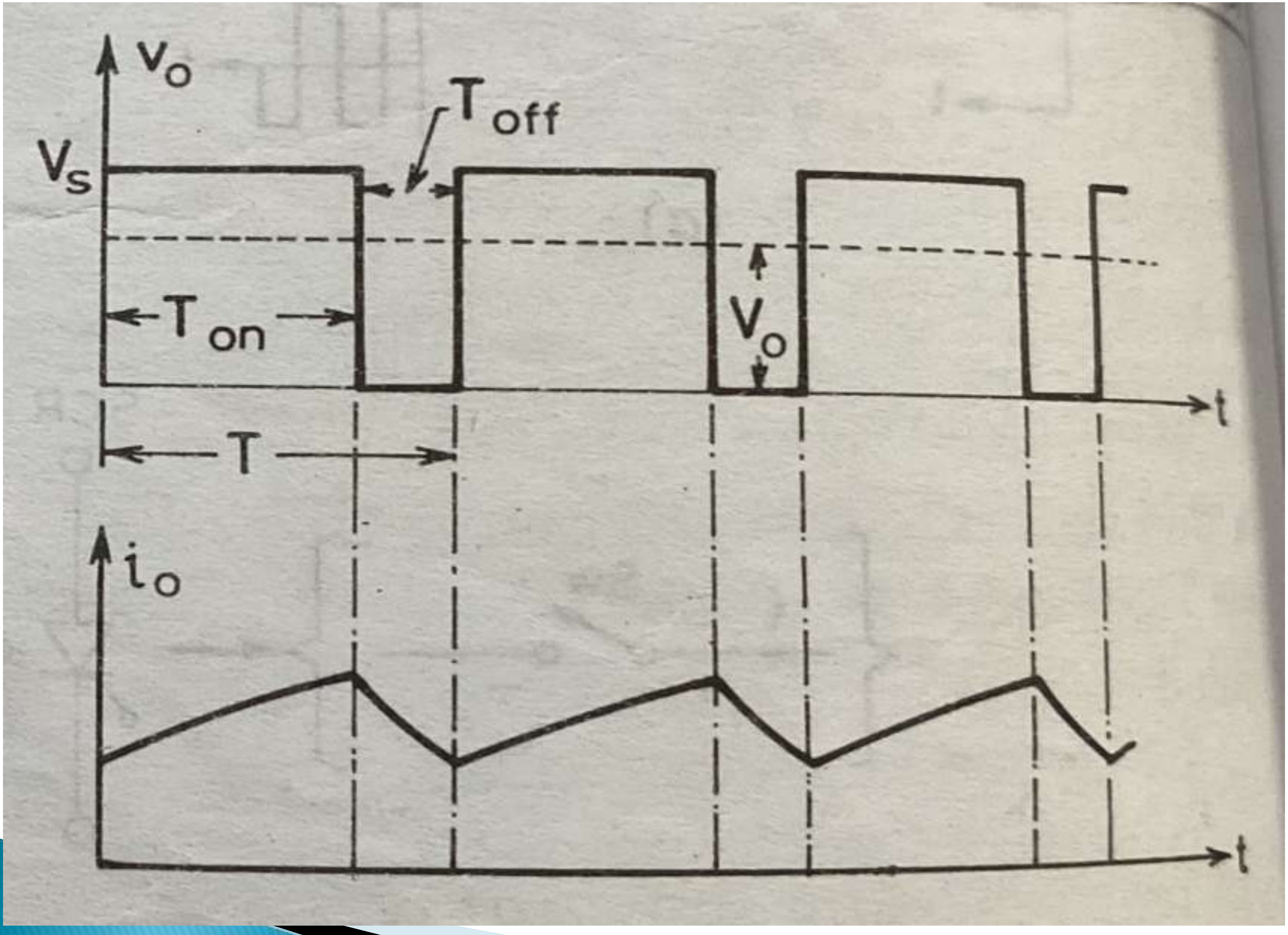


DC
Inverter
AC
DC
t
t
t


DC
Chopper
DC
t
t

Principle of Operation





v_o
T_{off}
V_s
T_{on}
V_o
t
T
i_o
t

$$V_0 = \frac{T_{on}}{T_{on}+T_{off}} V_s = \frac{T_{on}}{T} V_s = \alpha V_s$$

$$T_{on} = \text{on–time}\;;\; T_{off} = \text{off–time}$$

$$T = T_{on} + T_{off} = \text{chopping period}$$

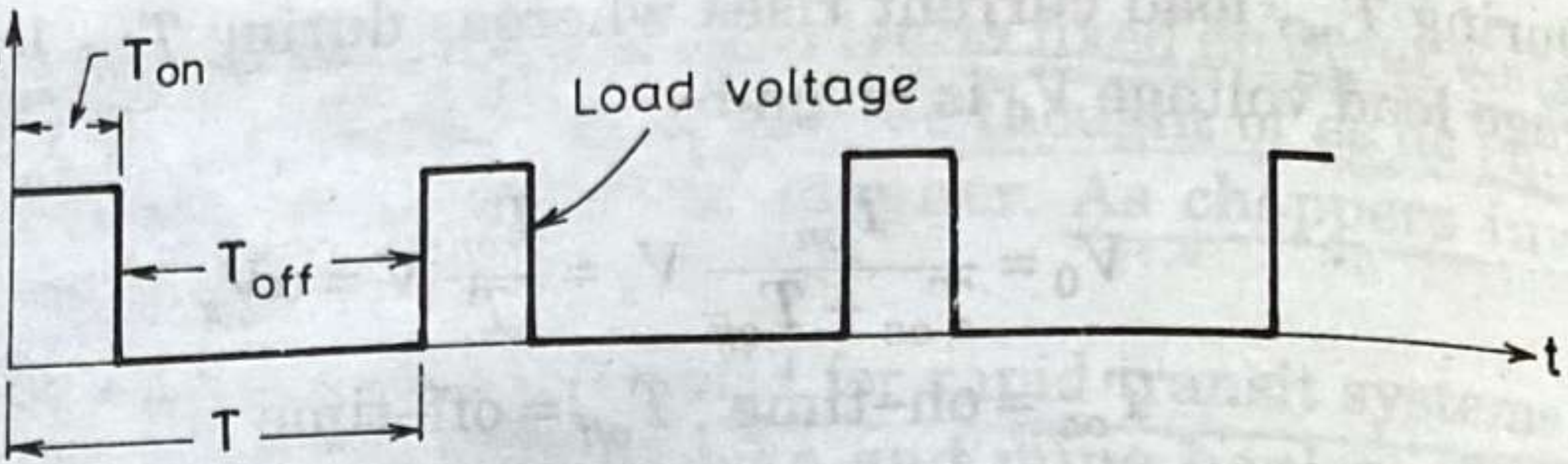
$$\boxed{\alpha = \frac{T_{on}}{T} = \text{duty cycle}}$$

$$V_0 = f \cdot T_{on} \cdot V_s$$

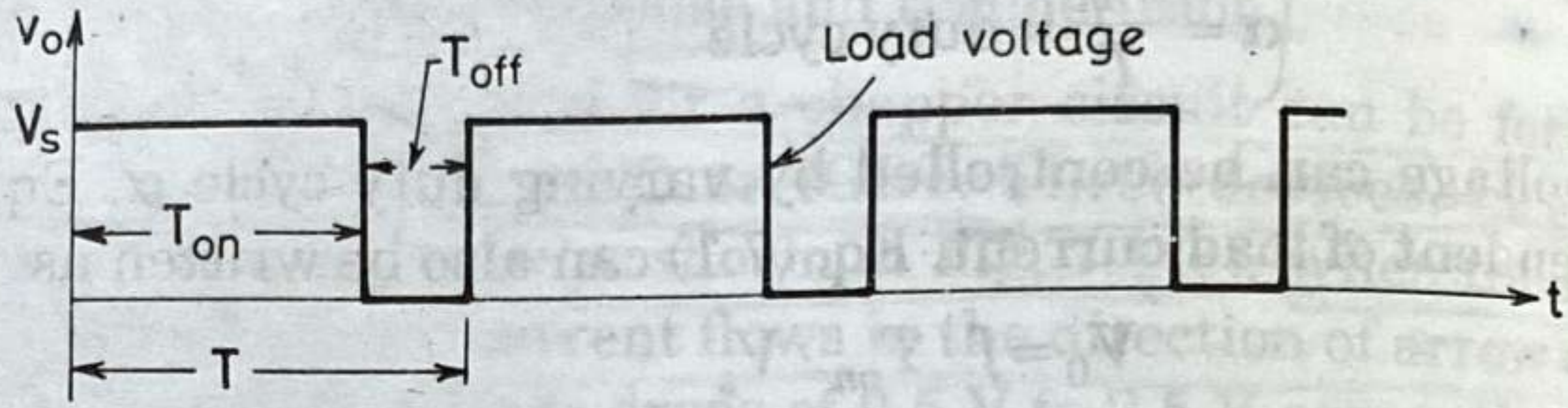
$$\boxed{f = \frac{1}{T} = \text{chopping frequency}}$$

Methods of Controlling Output Voltage

- **Constant Frequency Control**:
  - On Time T_{on} is varied but chopping Frequency is kept constant.

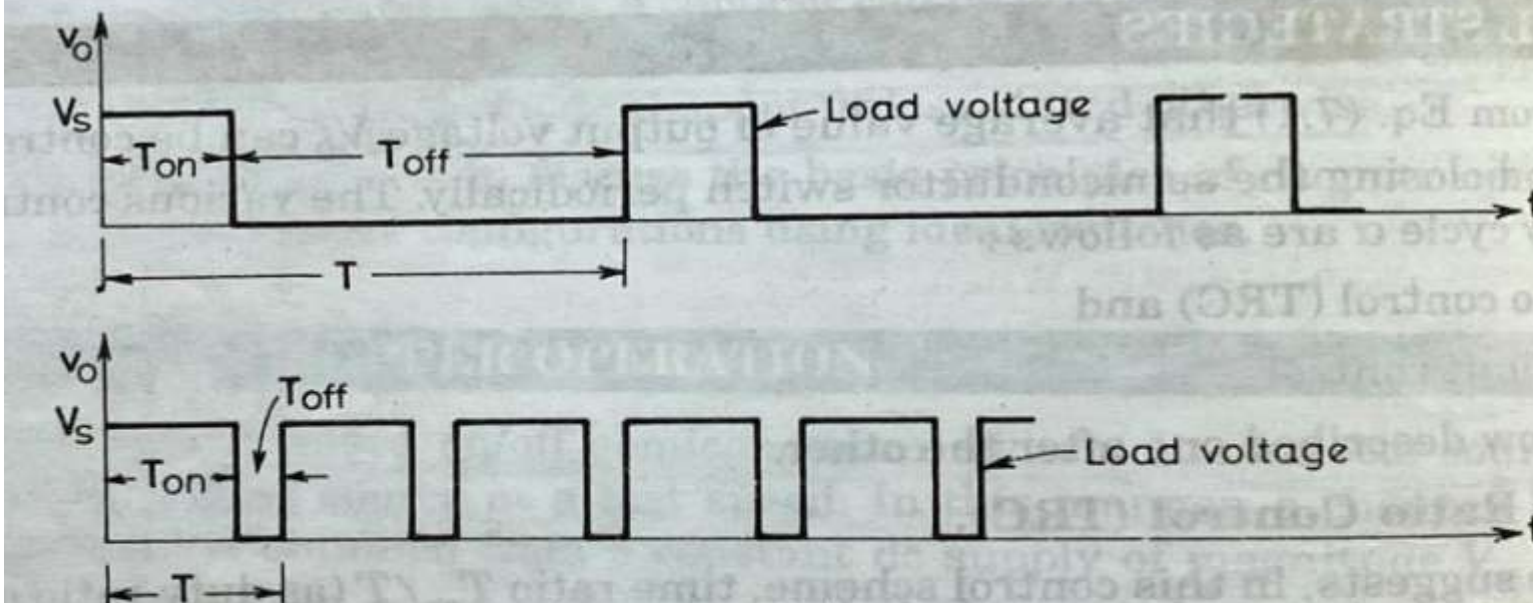


(a)

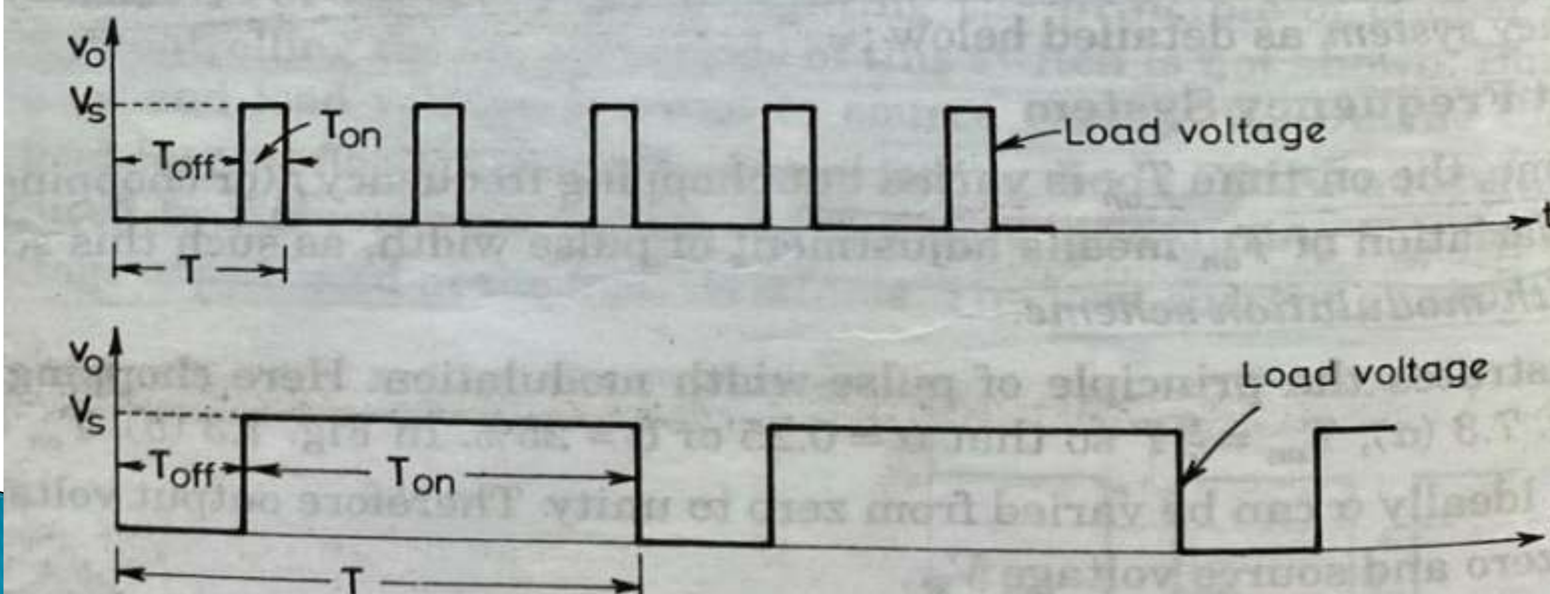


Methods of Controlling Output Voltage

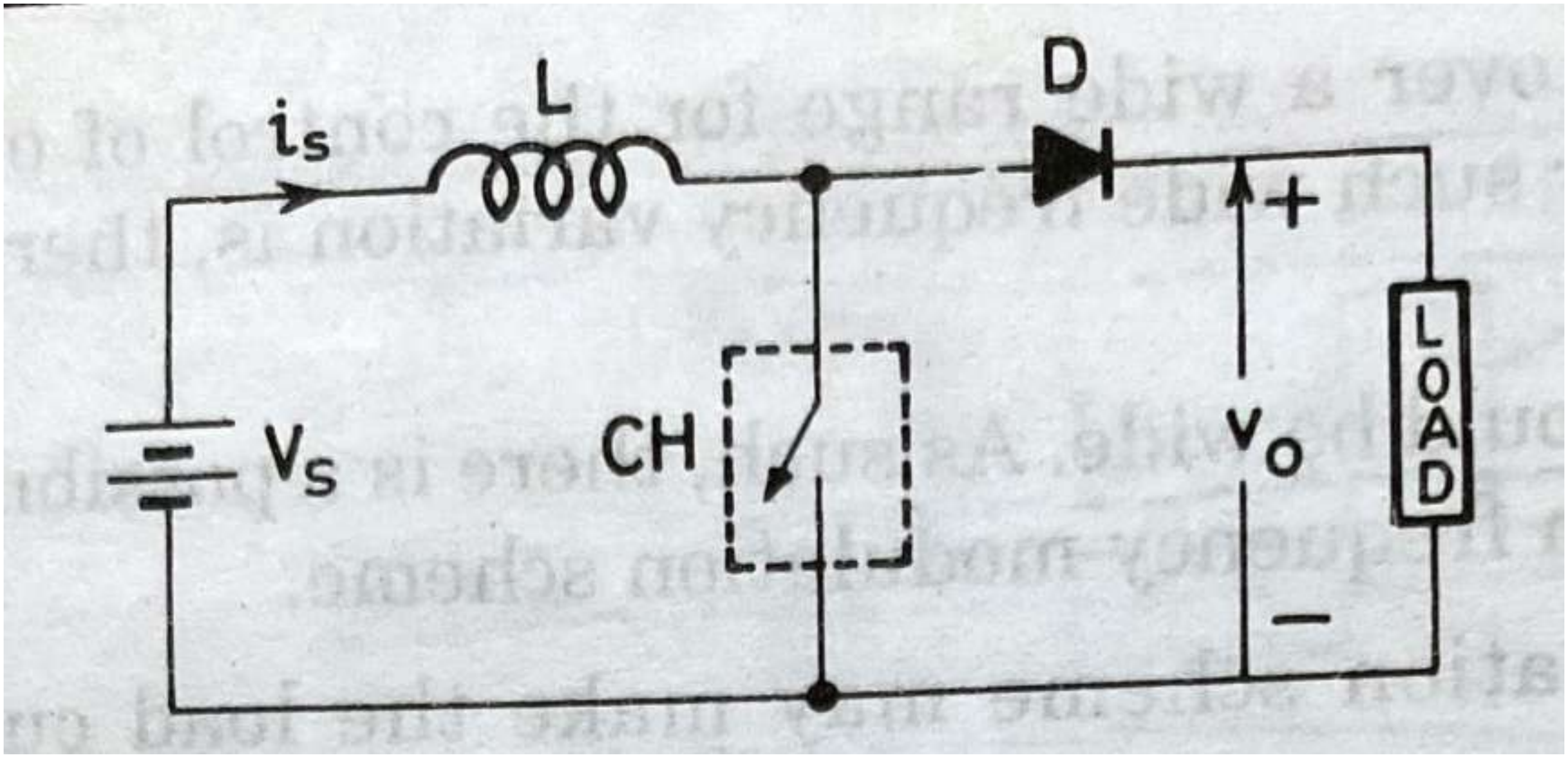
- **Variable Frequency Control**:
  - Either Time T_{on} or T_{off} is kept constant but chopping Frequency is varied.

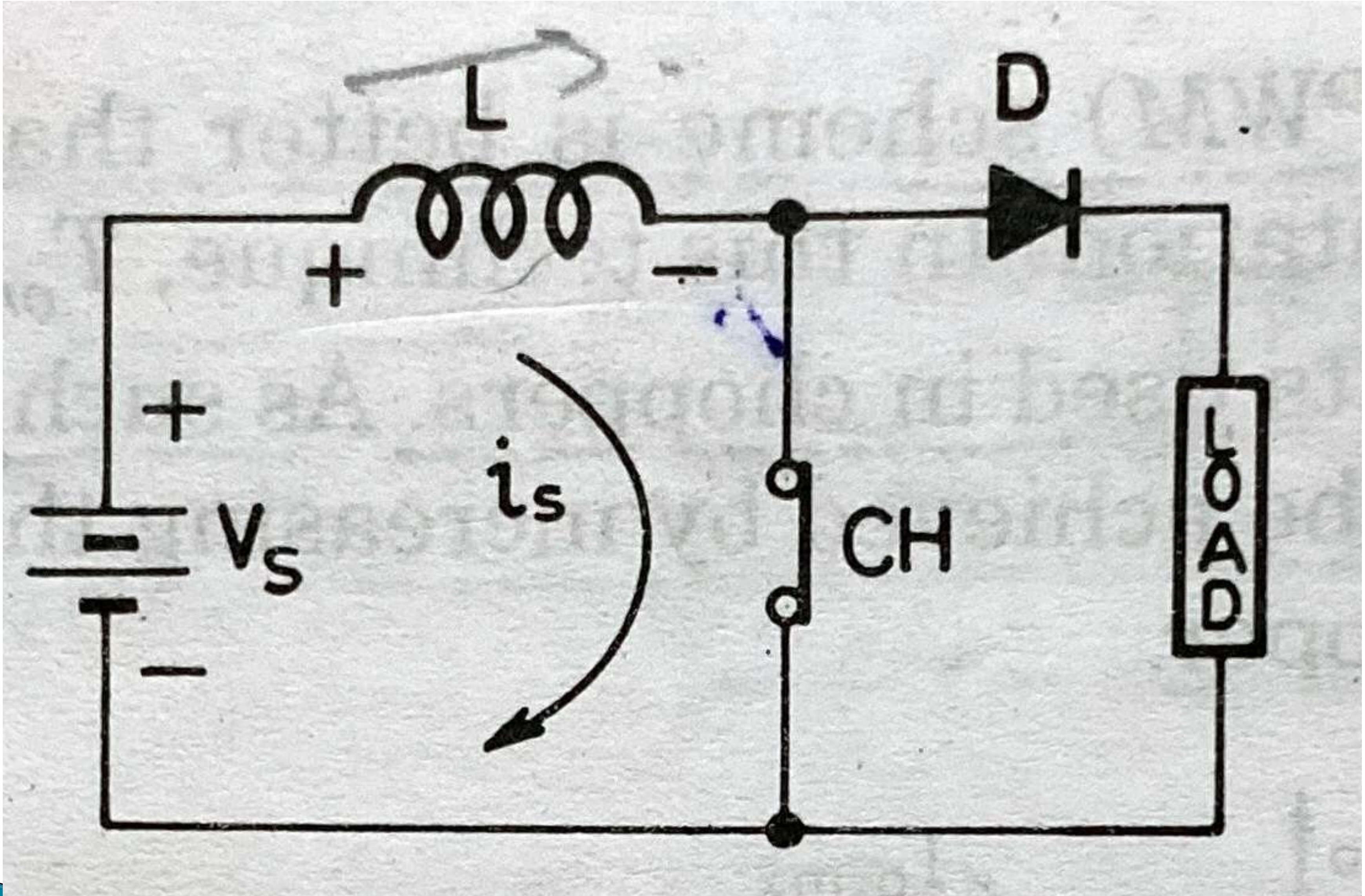


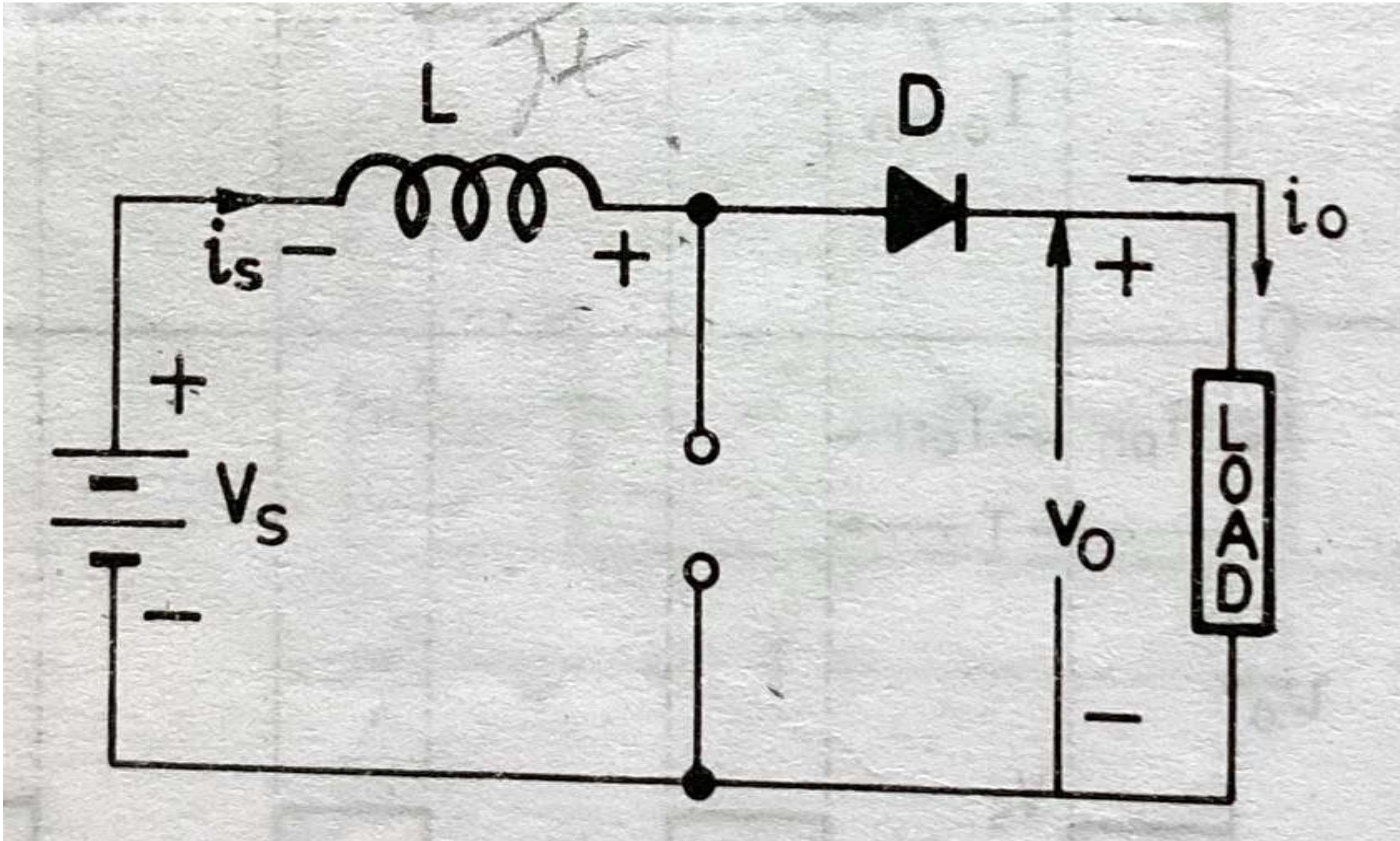
(a)



Step Up Chopper

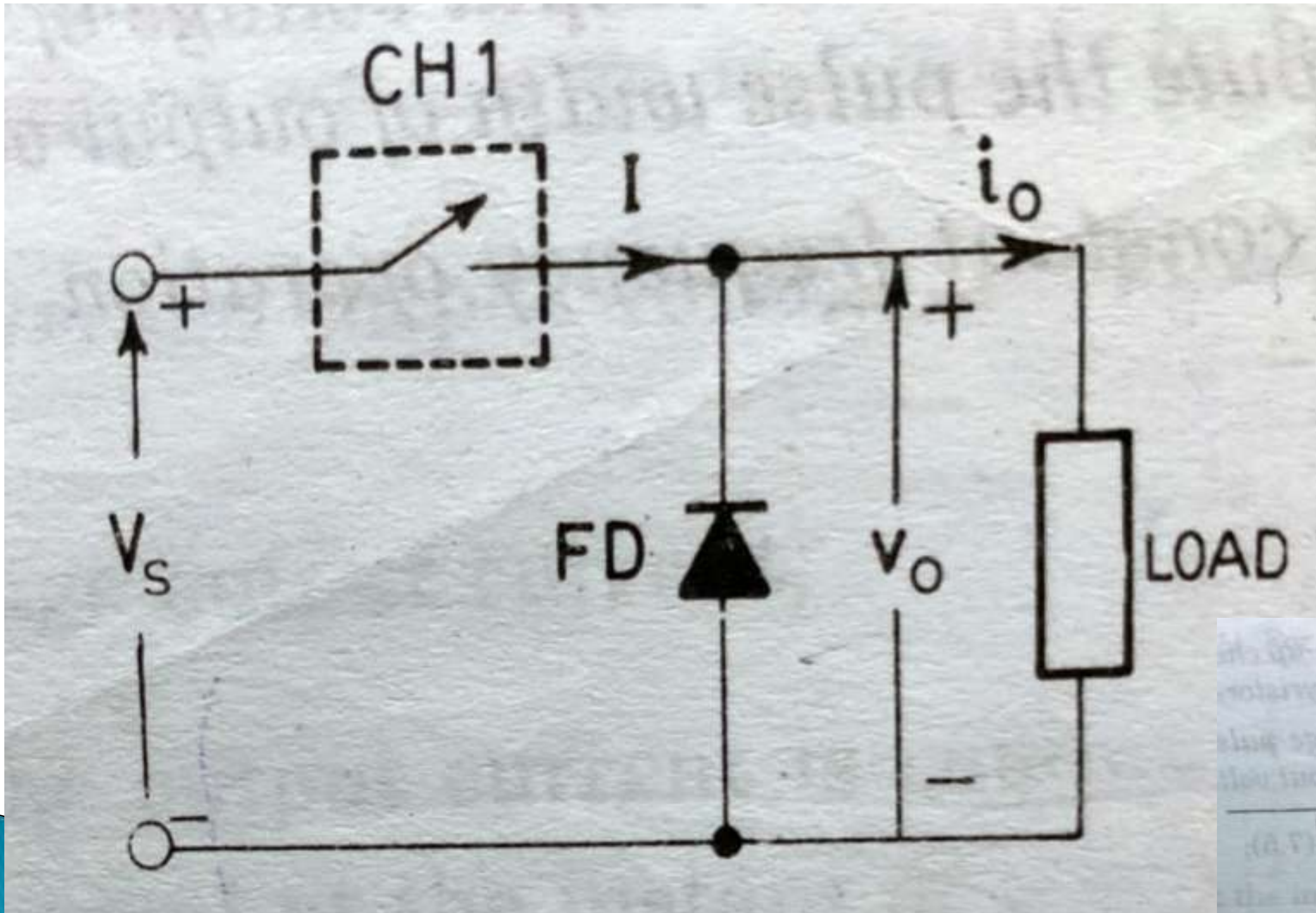


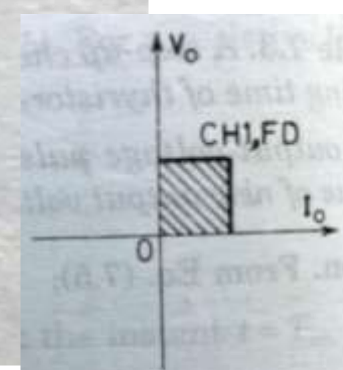

L
D
+
−
+
i_s
V_s
−
CH
LOAD



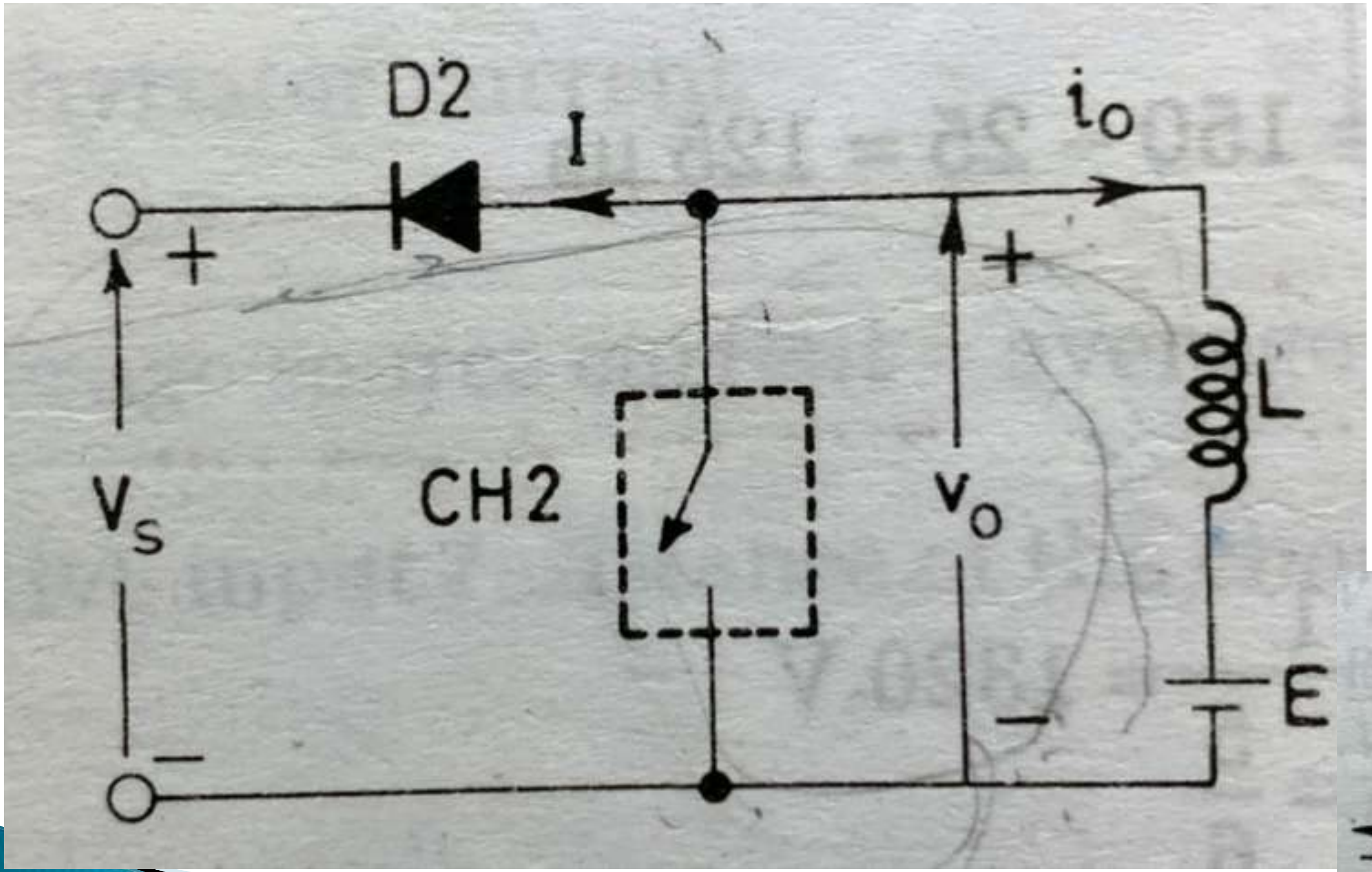
L
D
i_s
i_o
V_S
v_O
LOAD

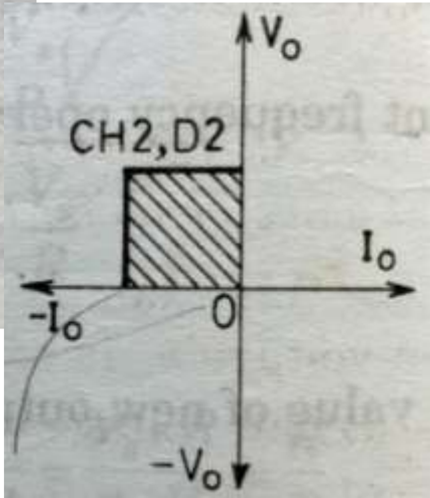
First Quadrant or Type A Chopper



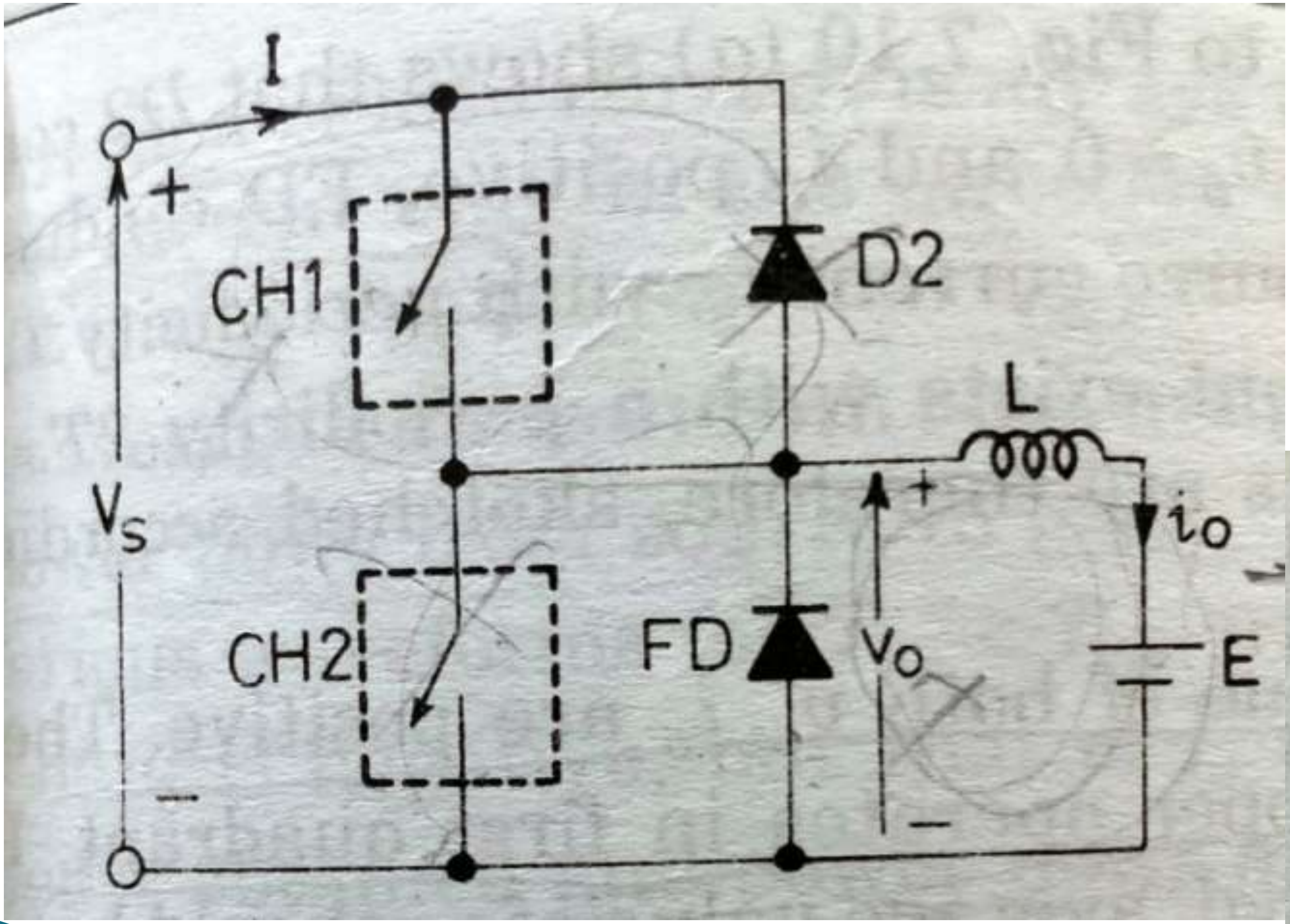


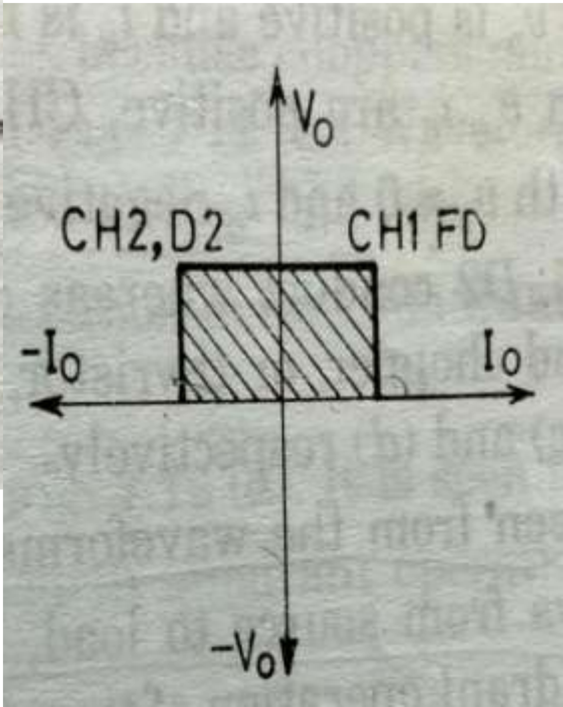
Second Quadrant or Type B Chopper



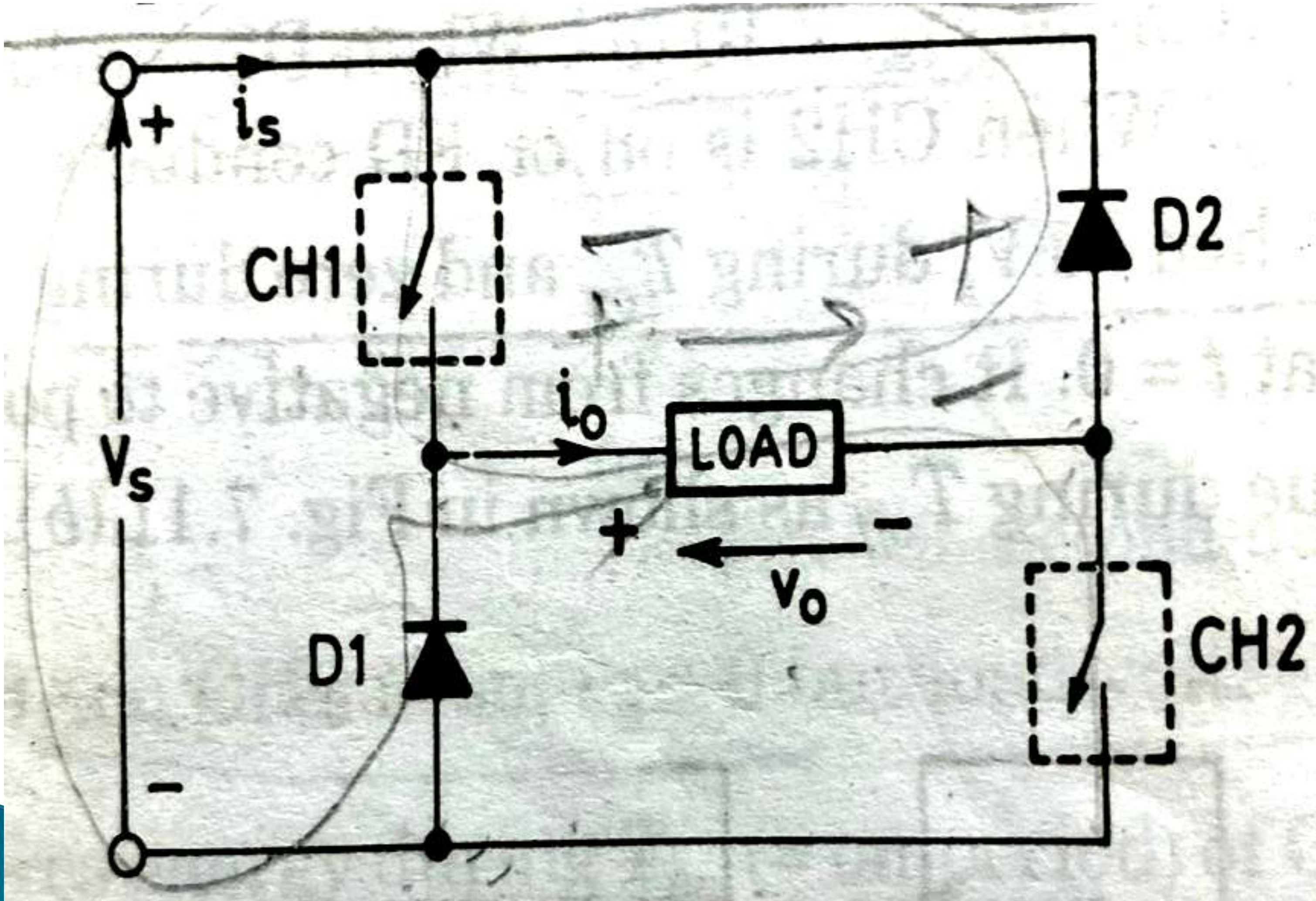


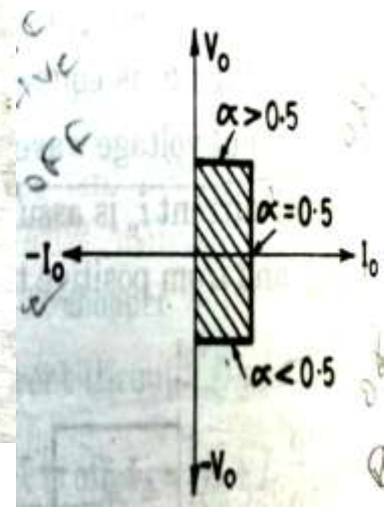
Type C Chopper



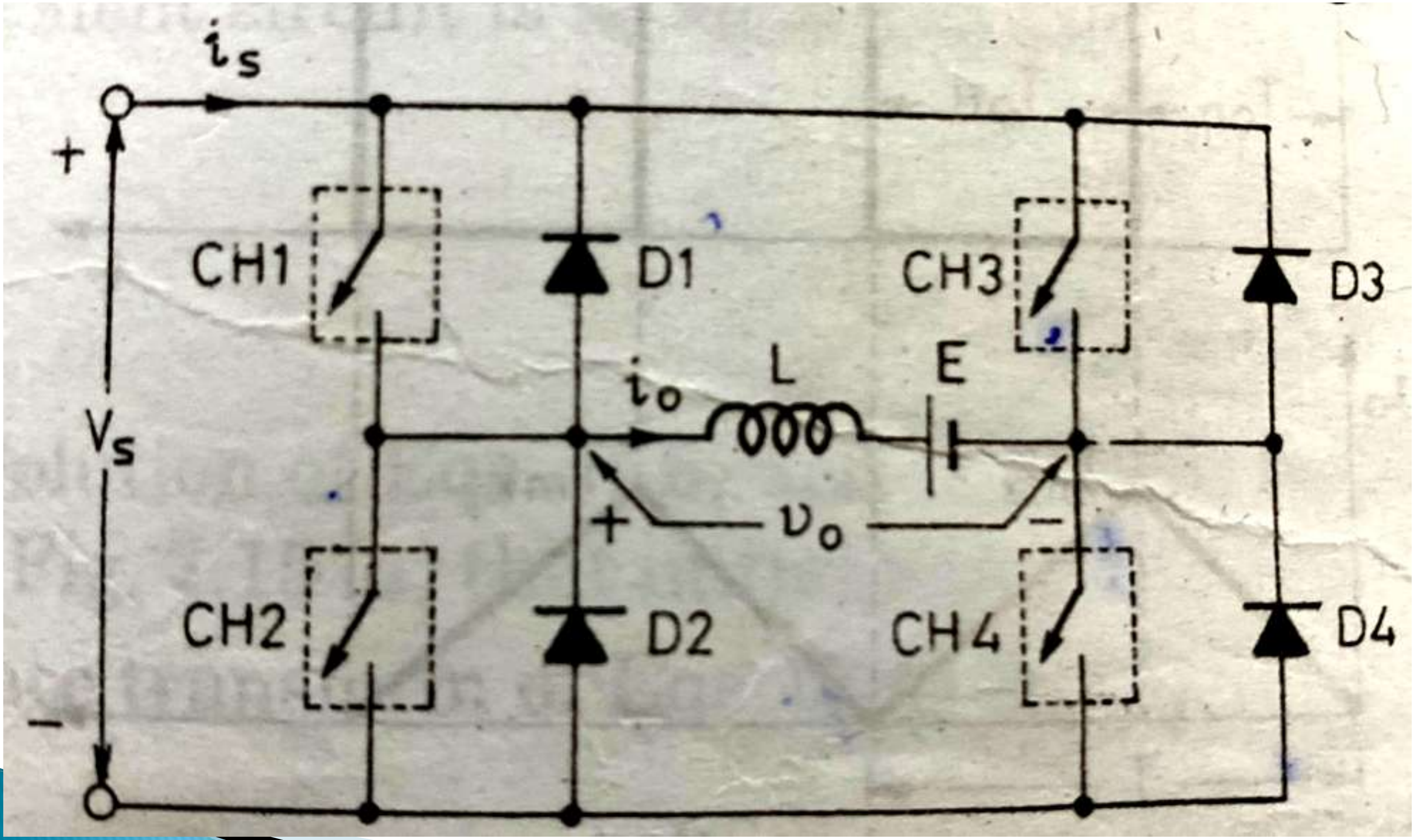


Type D Chopper

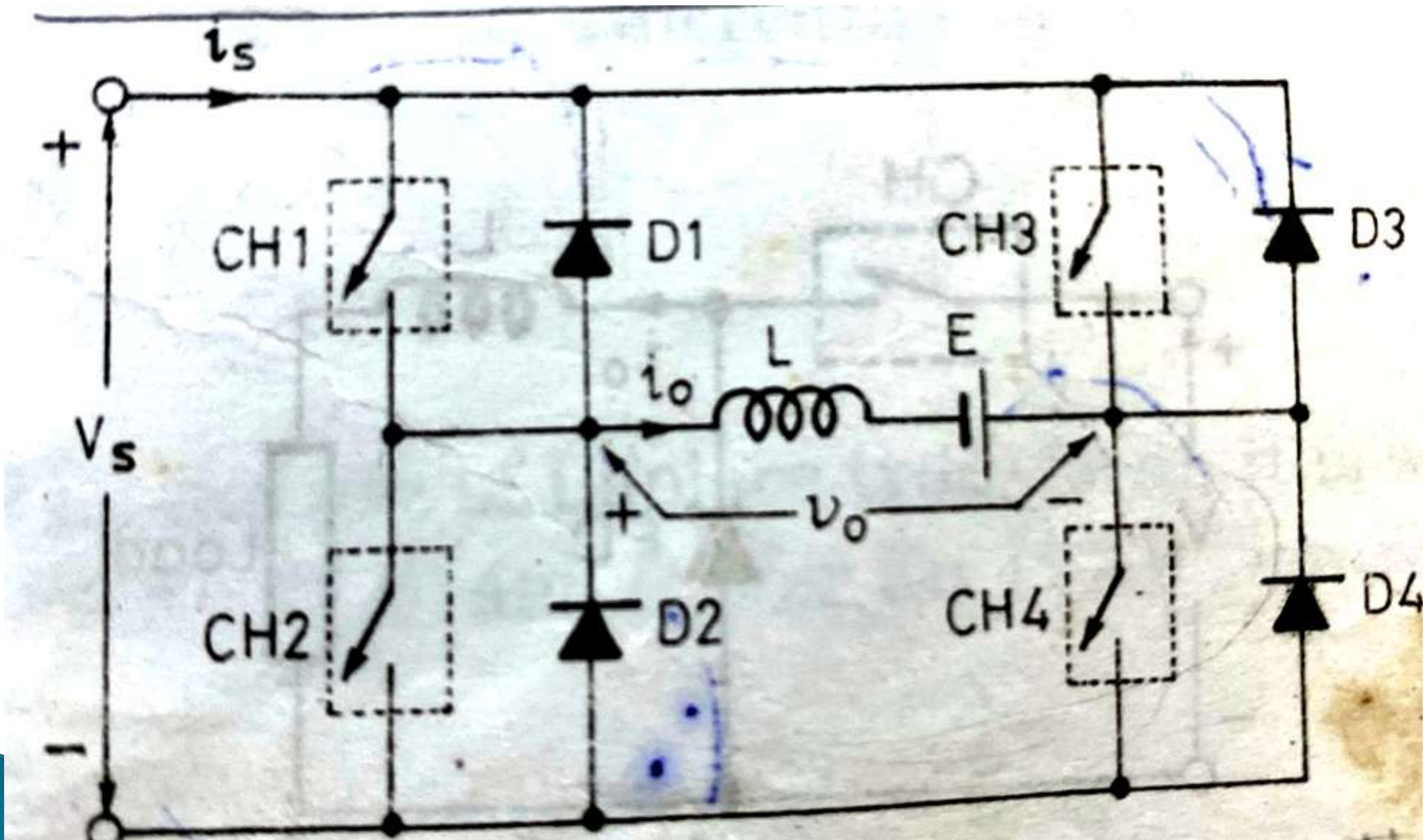


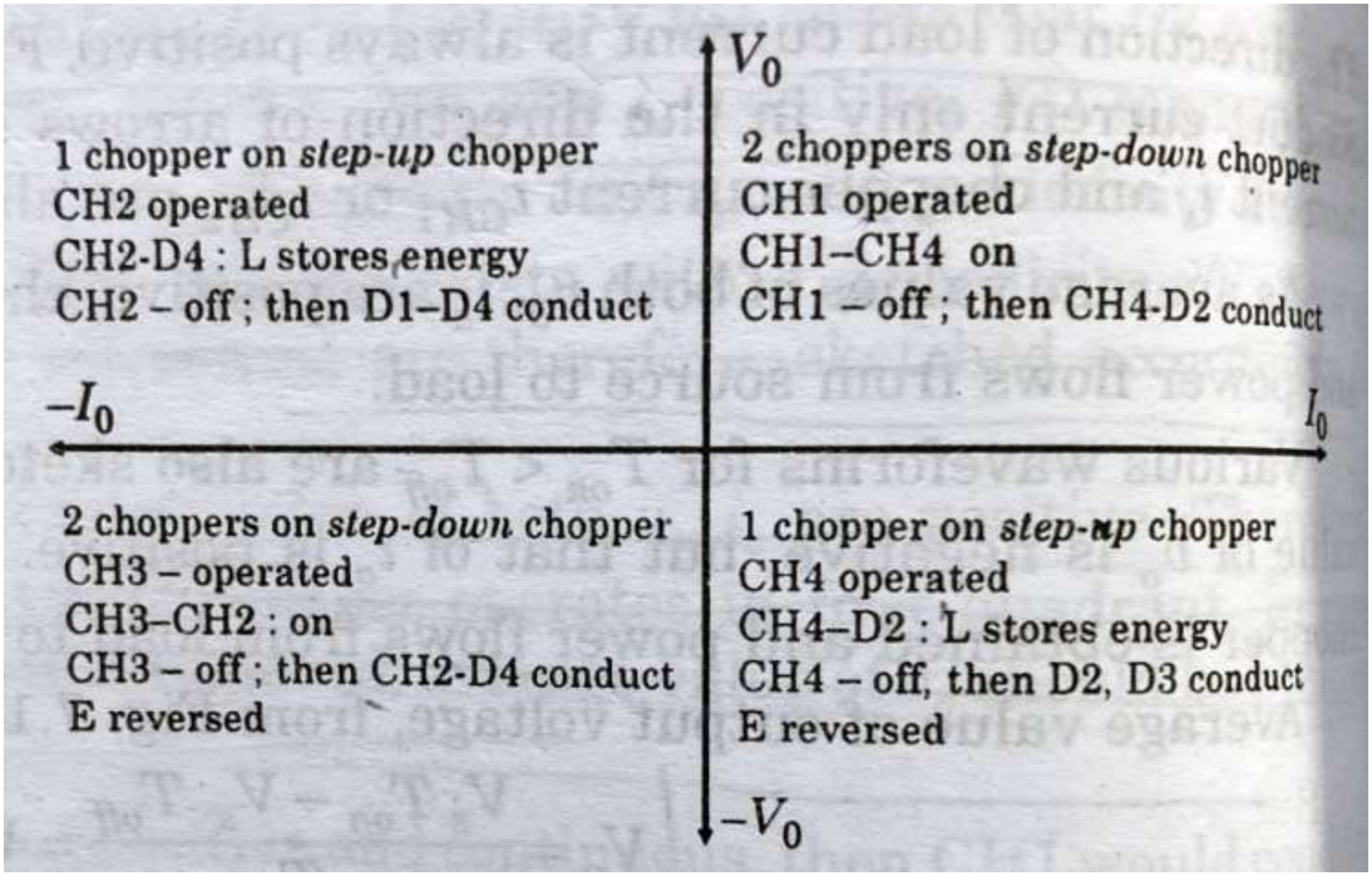


Four Qudrant or Type E Chopper



EMF E Reversed



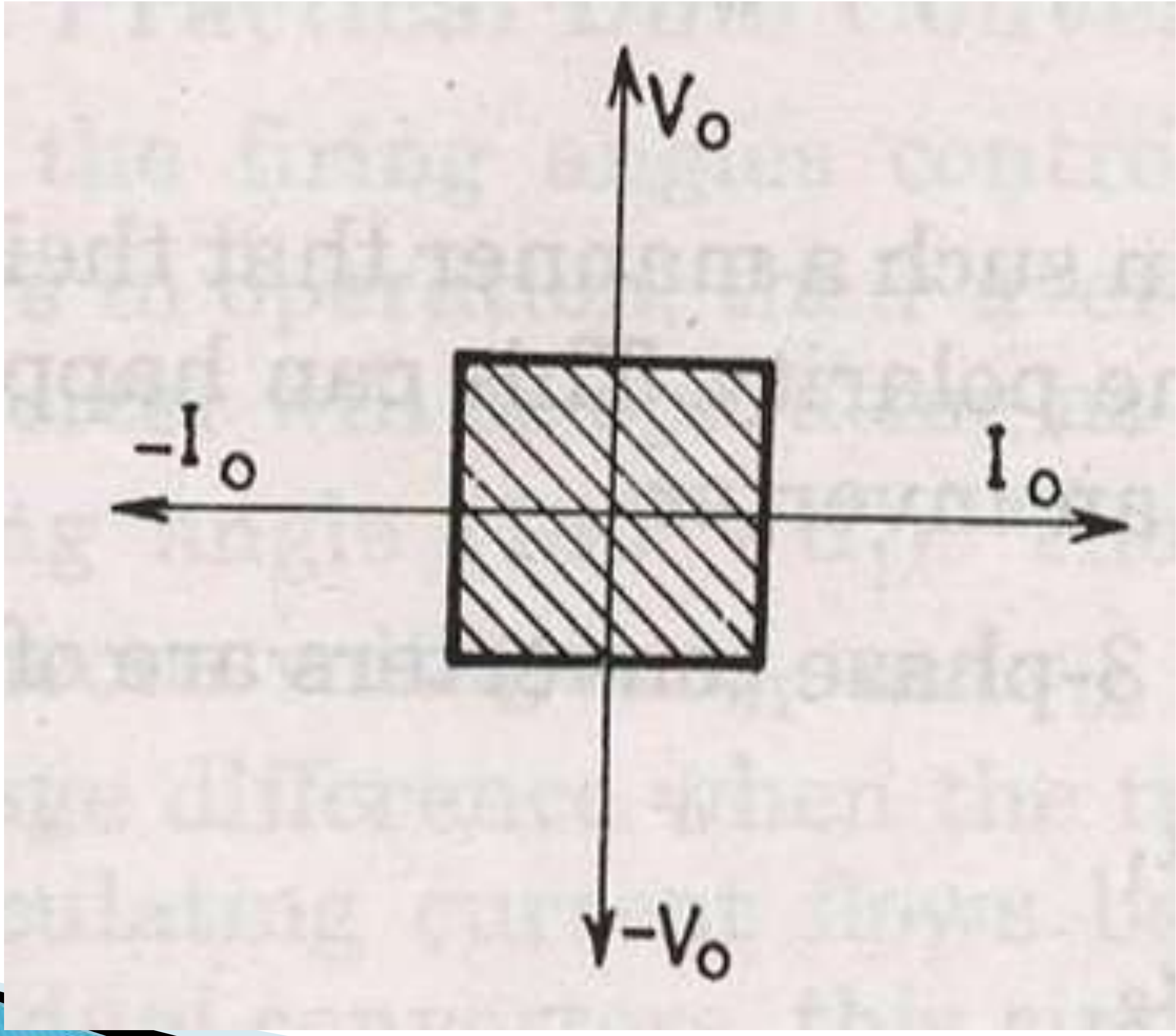


V_0
1 chopper on *step-up* chopper
CH2 operated
CH2-D4 : L stores energy
CH2 – off ; then D1–D4 conduct
2 choppers on *step-down* chopper
CH1 operated
CH1–CH4 on
CH1 – off ; then CH4-D2 conduct
$-I_0$
I_0
2 choppers on *step-down* chopper
CH3 – operated
CH3–CH2 : on
CH3 – off ; then CH2-D4 conduct
E reversed
1 chopper on *step-up* chopper
CH4 operated
CH4–D2 : L stores energy
CH4 – off, then D2, D3 conduct
E reversed
$-V_0$

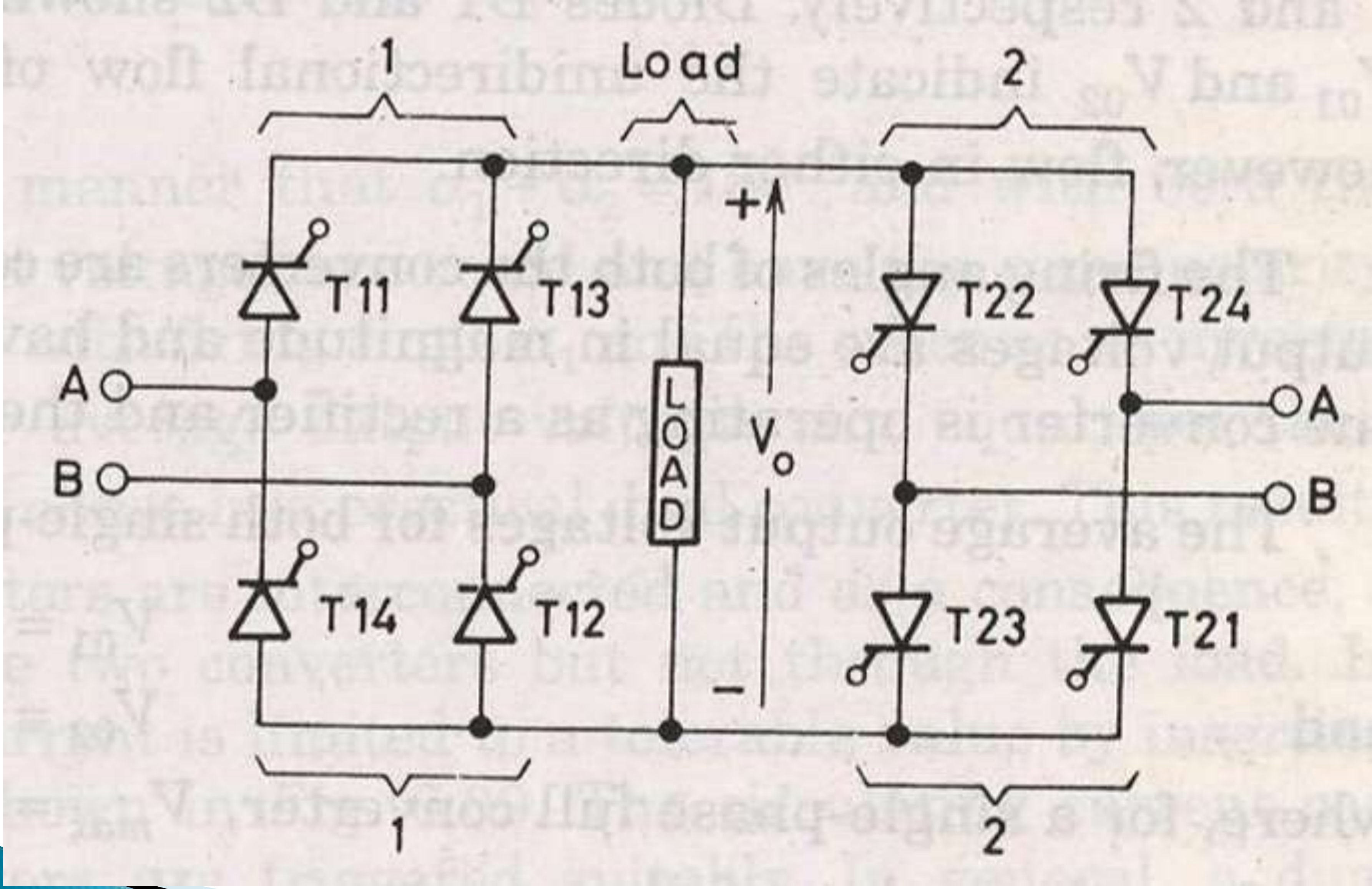
Dual Converters

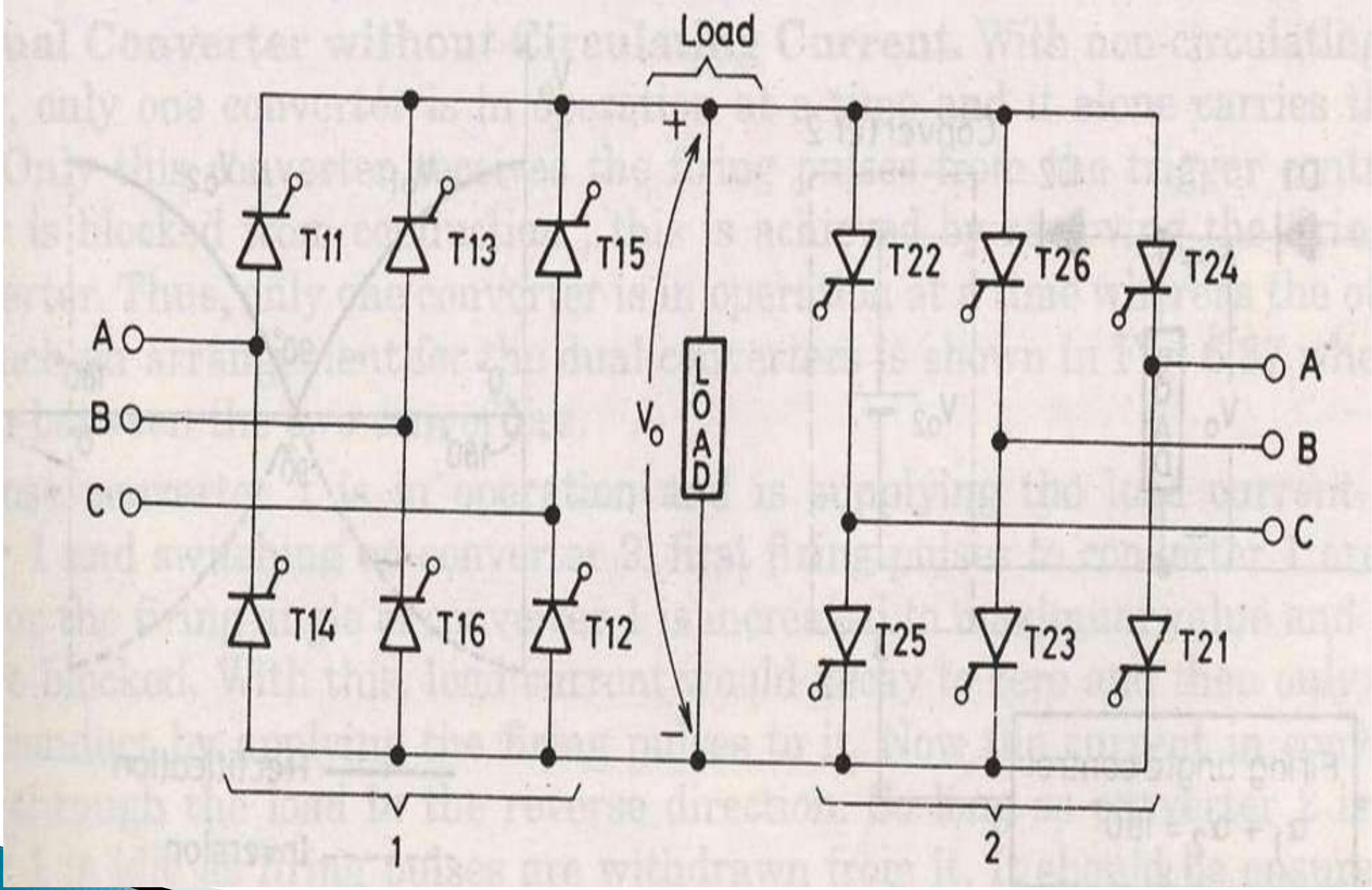
Dual Converter

- A Full converter can operate in Two quadrants.
- If four Quadrant operation is required, without any mechanical changeover switch, two full converters can be connected back to back to load circuit.
- Such an arrangement using two full converters in anti parallel and connected to the same dc load is called a Dual Converter.



V_o
$-I_o$
I_o
$-V_o$


1
Load
2
T11
T13
T22
T24
A
B
LOAD
V_o
+
−
T14
T12
T23
T21
A
B
1
2


Load
+
T11
T13
T15
T22
T26
T24
A
B
C
A
B
C
V_o
LOAD
T14
T16
T12
T25
T23
T21
−
1
2

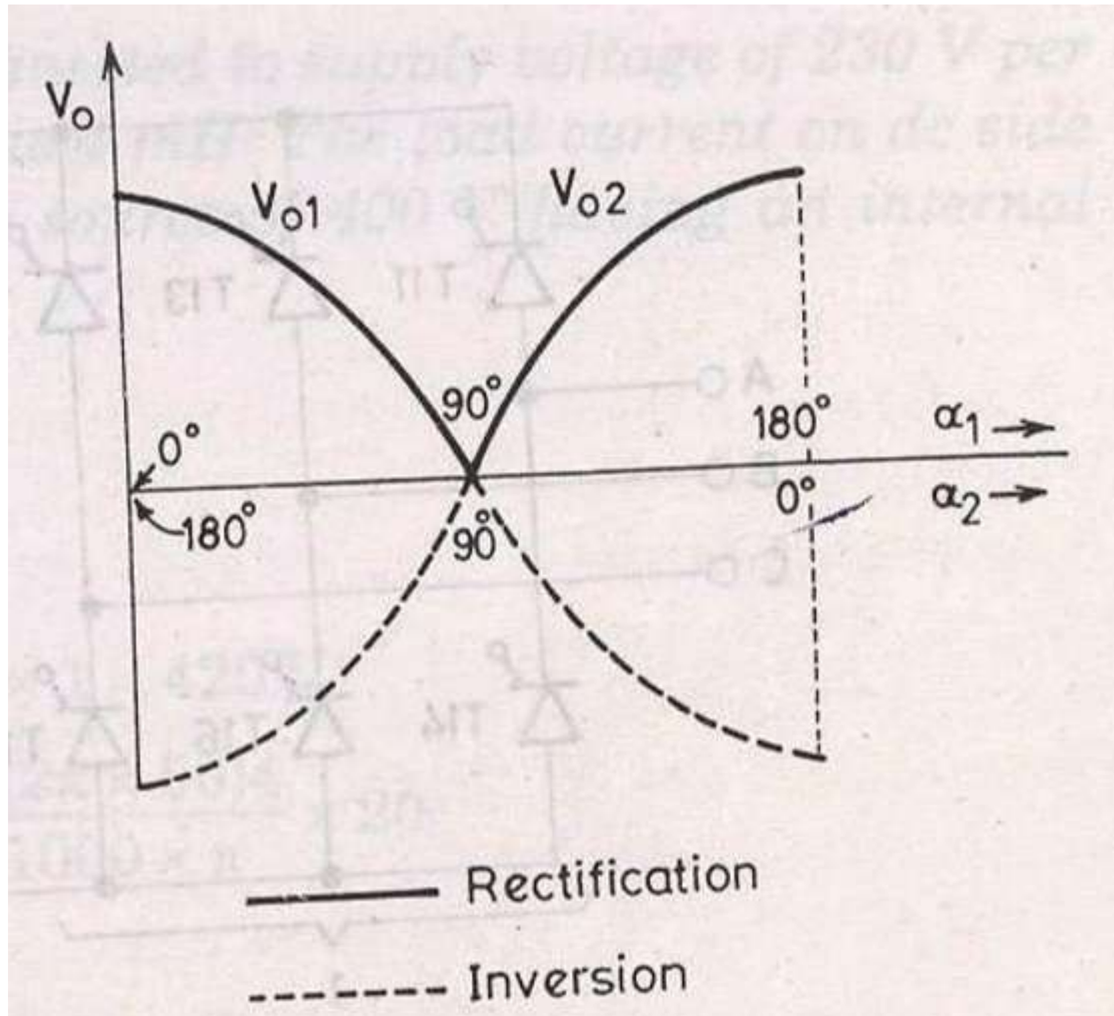
$$V_0 = V_{01} = -V_{02}$$

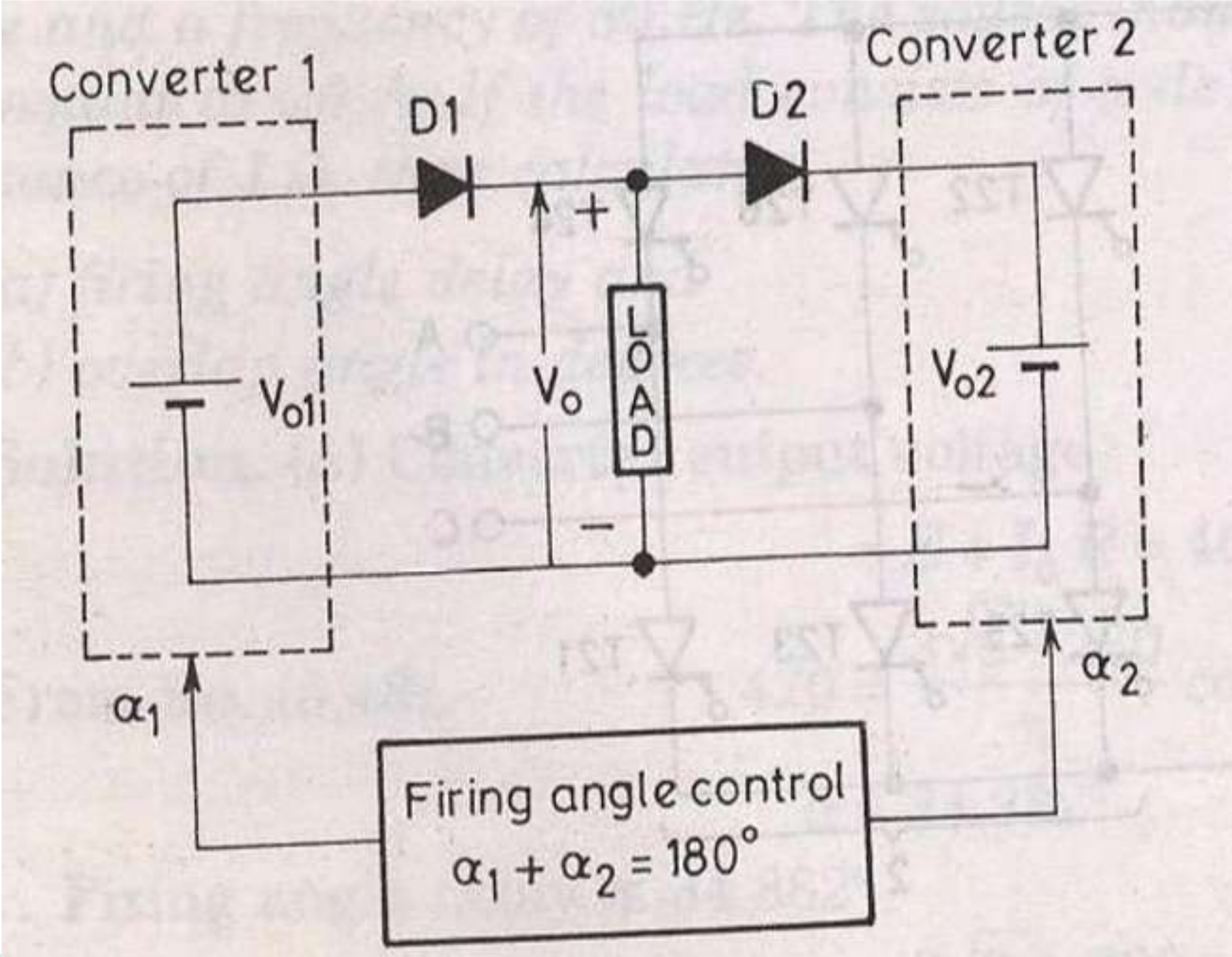
$$V_{max} \cos \alpha_1 = - V_{max} \cos \alpha_2$$

$$\cos \alpha_1 = - \cos \alpha_2 = \cos (180 - \alpha_2)$$

$$\alpha_1 + \alpha_2 = 180°$$

$$V_{01} = V_{max} \cos \alpha_1$$
$$V_{02} = V_{max} \cos \alpha_2$$




Converter 1
D1
D2
Converter 2
+
LOAD
V_{o1}
V_o
V_{o2}
−
α_1
α_2
Firing angle control
$\alpha_1 + \alpha_2 = 180°$

Types of Dual Converters

- Non Circulating Current Type
- Circulating Current Type

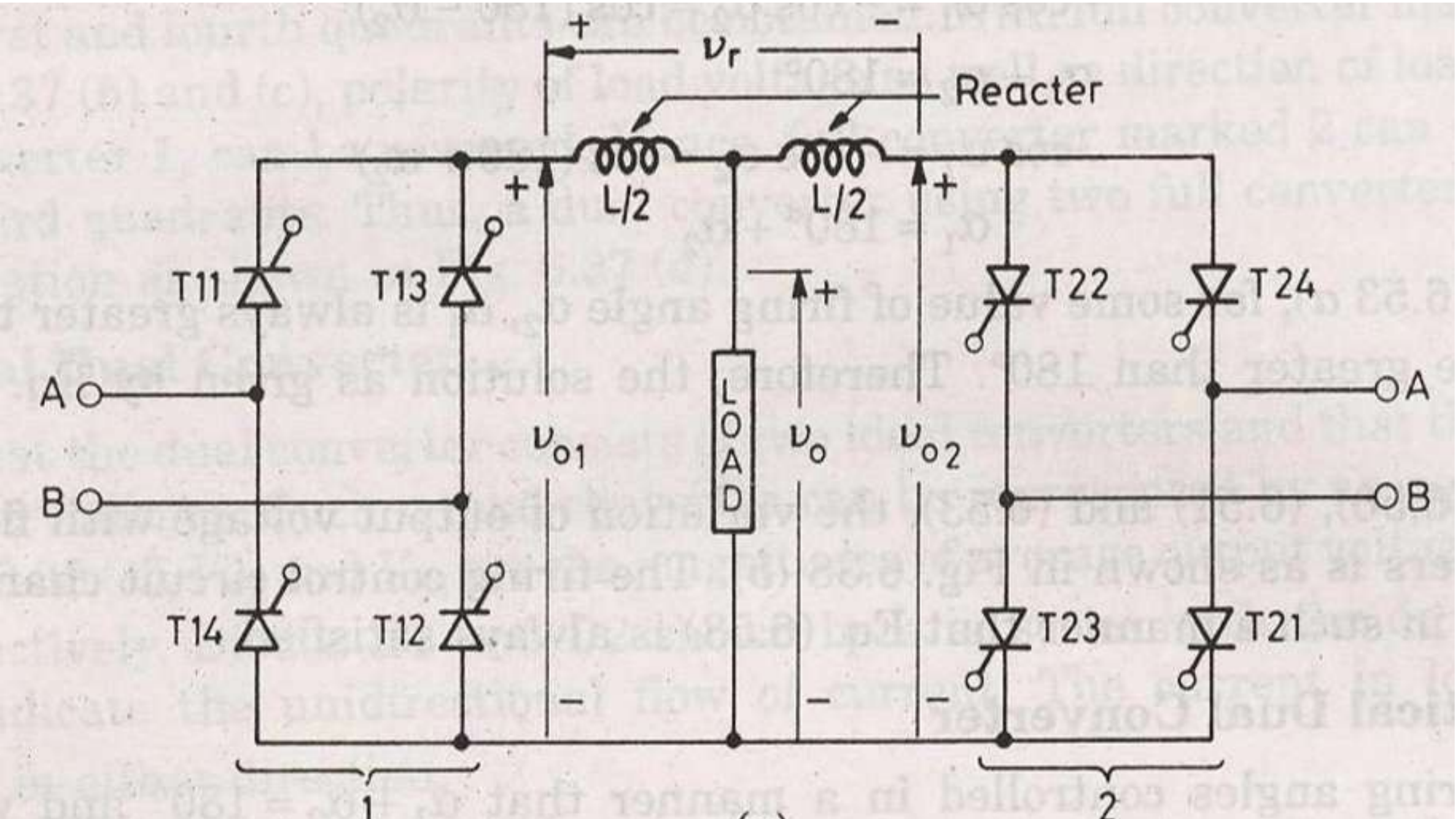
Non Circulating Current Type

- Only one converter operates at a time and carries the load current.
- Before second converter is triggered, it is necessary to make load current zero.

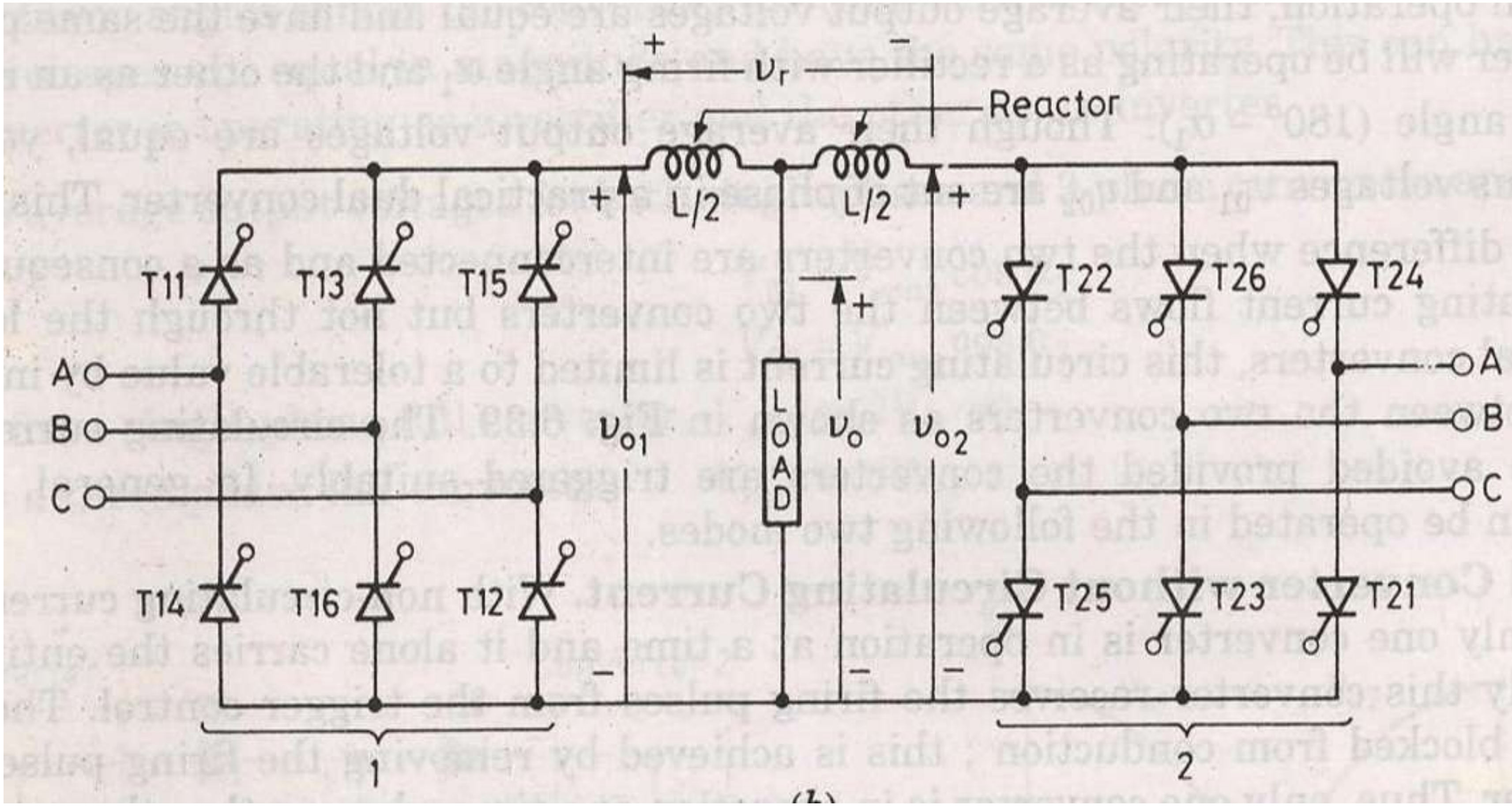
Circulating Current Type

- Both the converters are operated simultaneously
- As the instantaneous output voltage of both converters is out of phase, therefore circulating current flows between them.
- Inductors are used to limit the circulating current.

Circulating Current Type



(a)


+
−
v_r
Reactor
L/2
L/2
+
+
T11
T13
T15
T22
T26
T24
+
A
B
C
v_{o1}
LOAD
v_o
v_{o2}
A
B
C
T14
T16
T12
T25
T23
T21
−
−
−
1
2

Cycloconverters

Cycloconverter

- A device which converts input power at one frequency to output power at different frequency, with one stage conversion is called cycloconverter.
- Cycloconverter is a one stage frequency changer.

Types of Cycloconverters

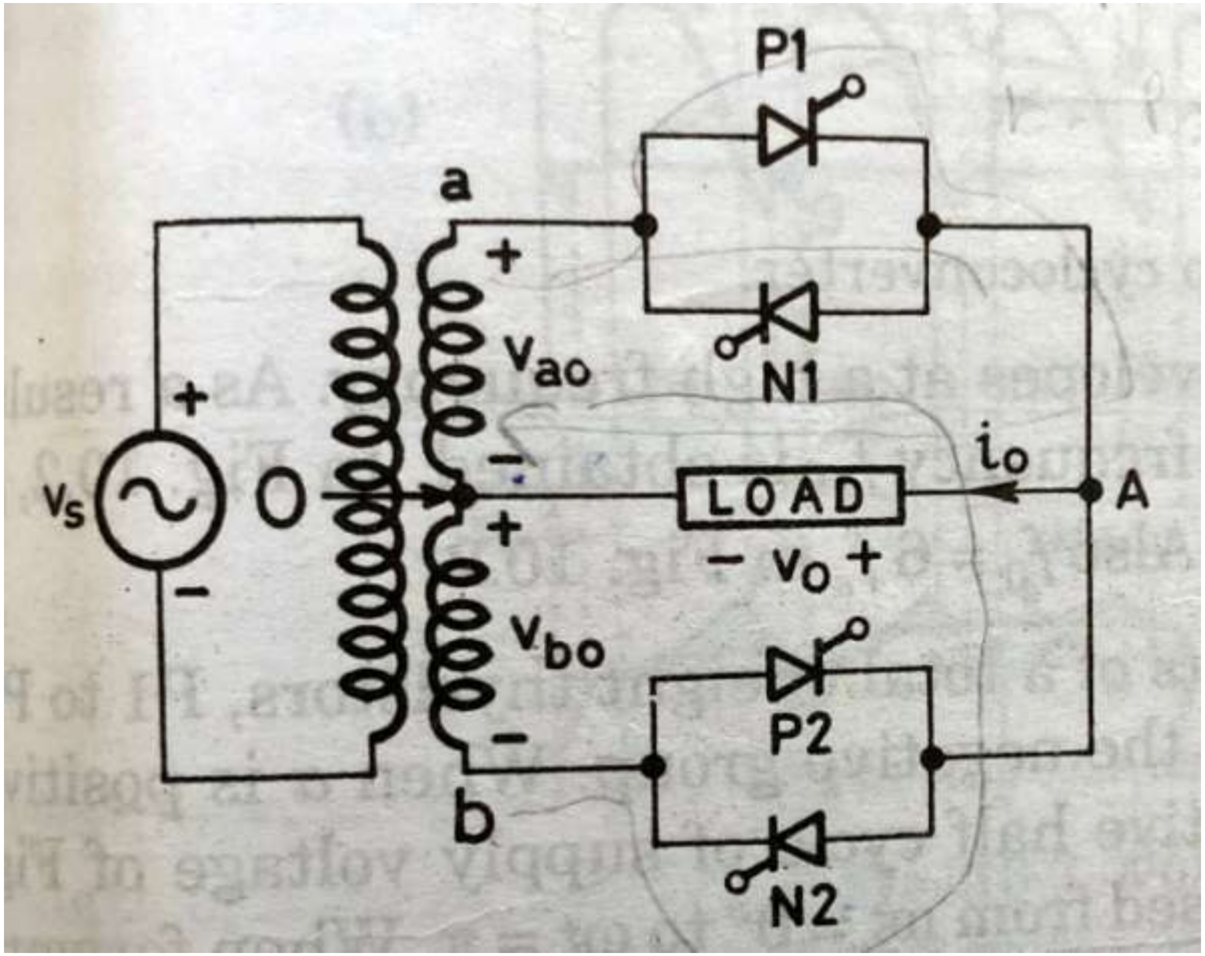
- Step Down Cycloconverters
  - Output frequency is lower than supply frequency

- Step Up Cycloconverters
  - Output frequency is higher than supply frequency

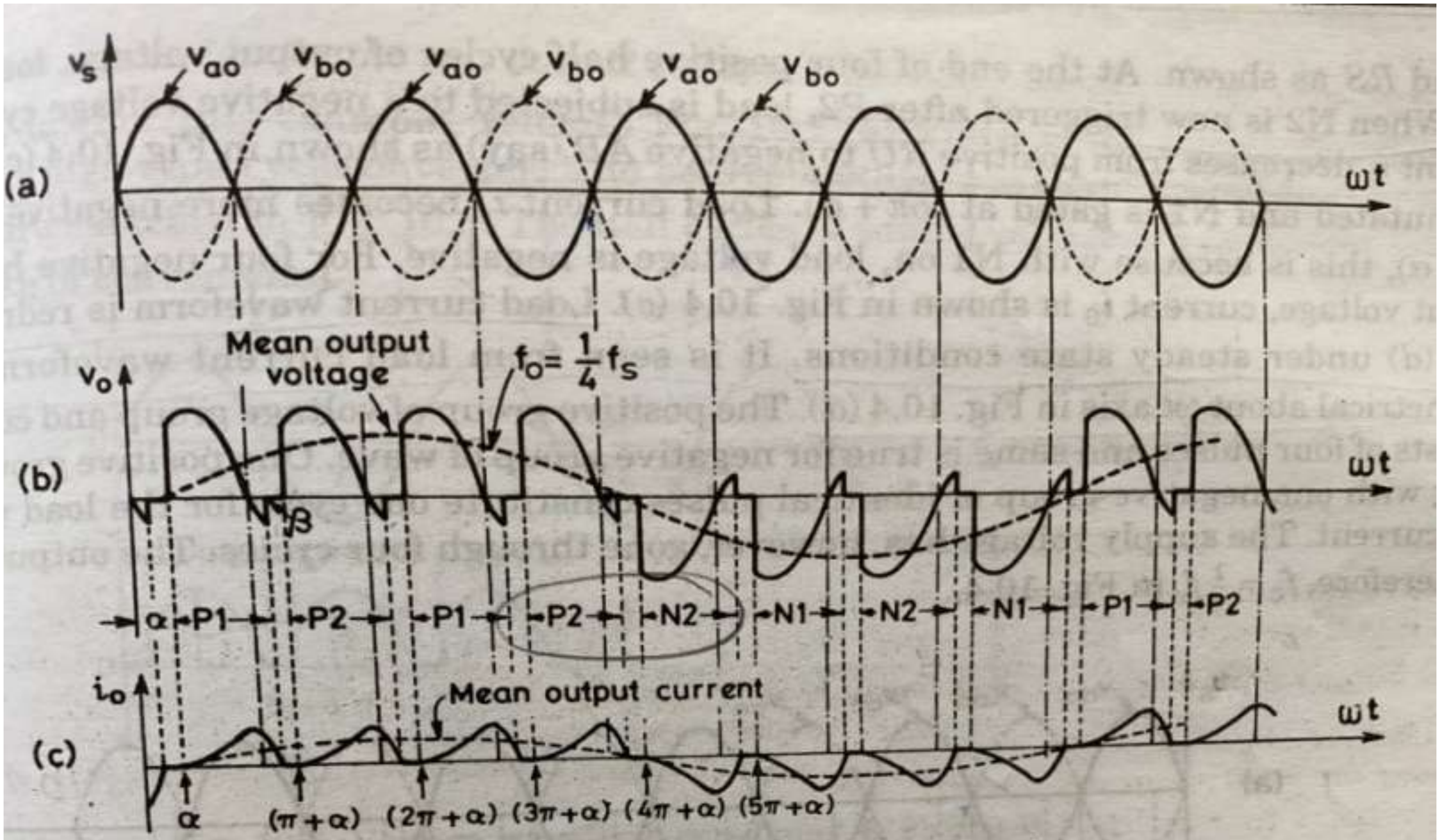
Applications of Cycloconverters

- Speed control of high power ac drives
- Induction Heating
- Static Var Compensation
- For converting variable speed alternator voltage to constant frequency output voltage for use as power supply in aircraft or shipboards.

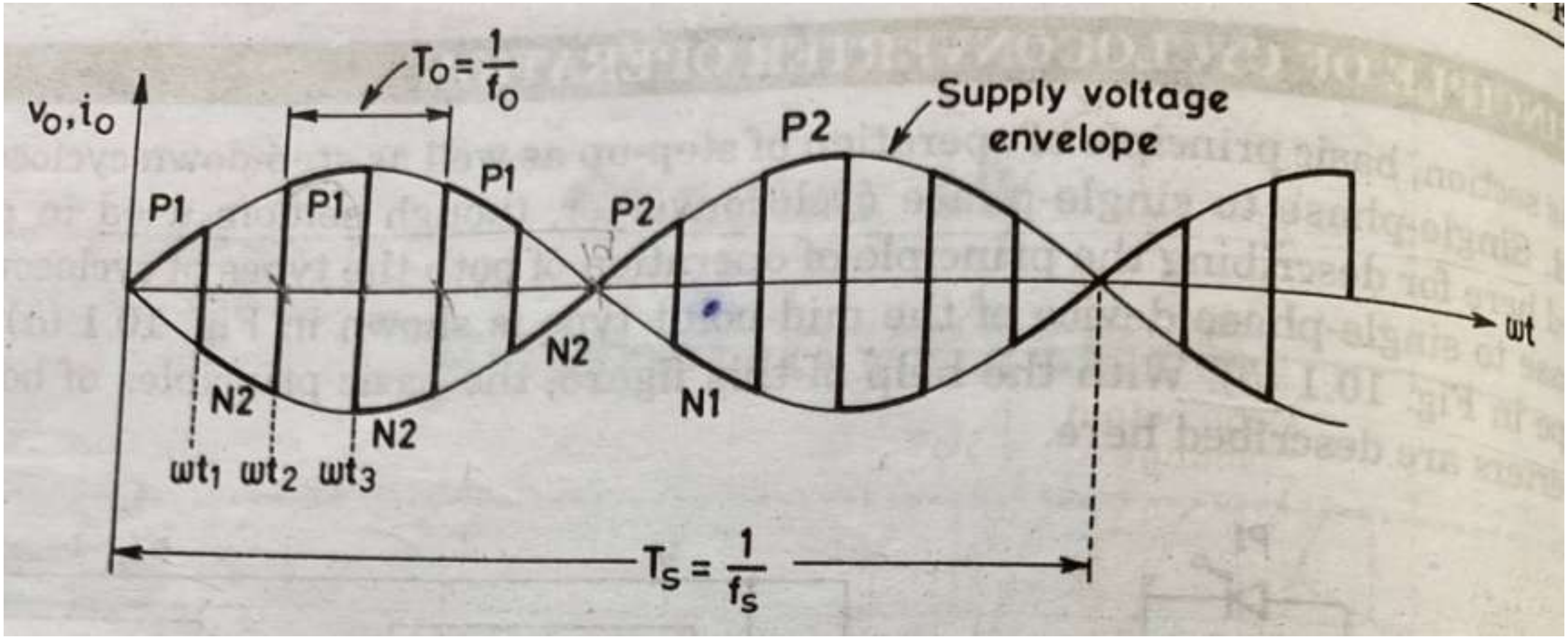
Principle of Operation



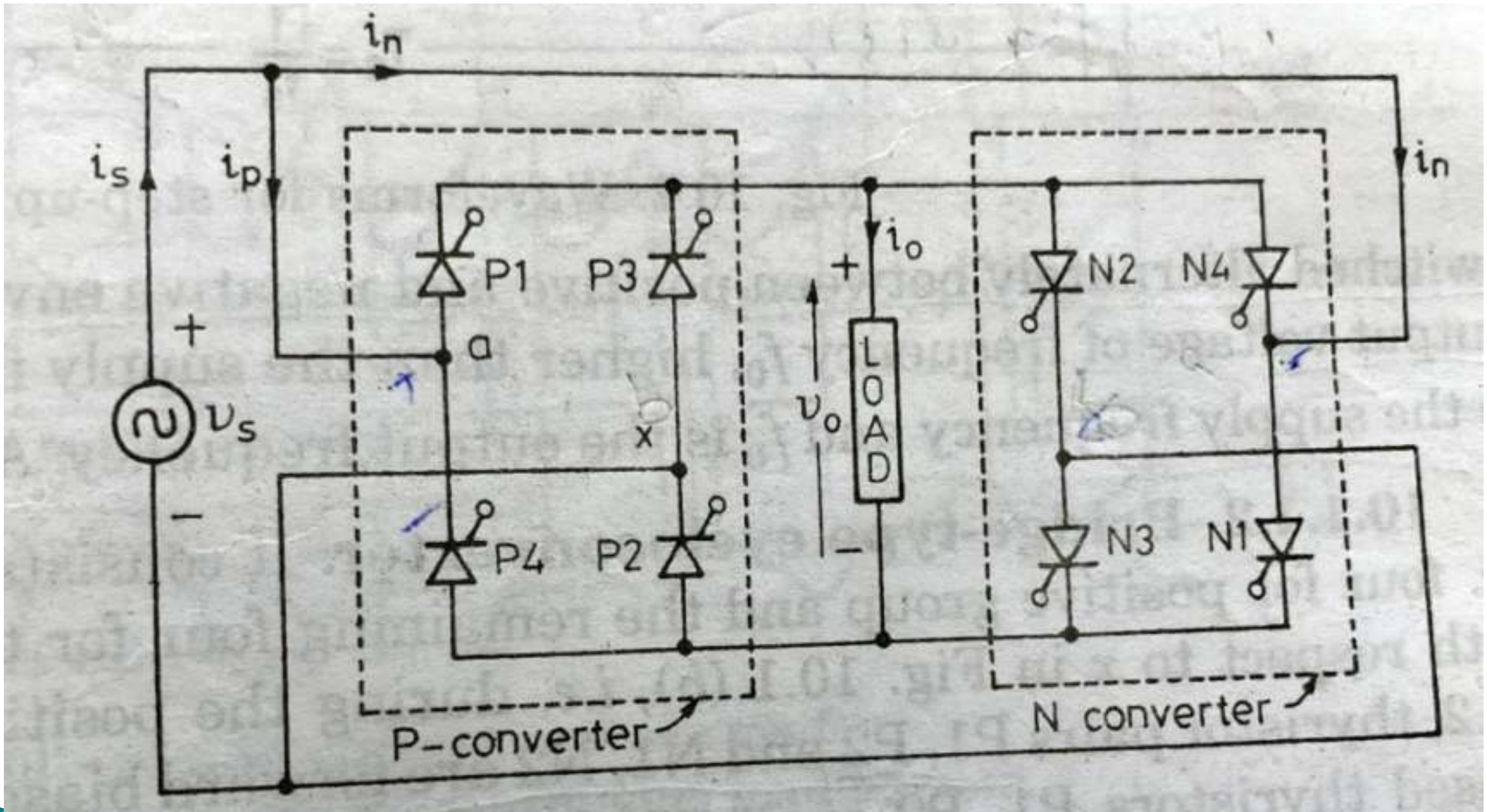
Output of Step Down Cycloconverter



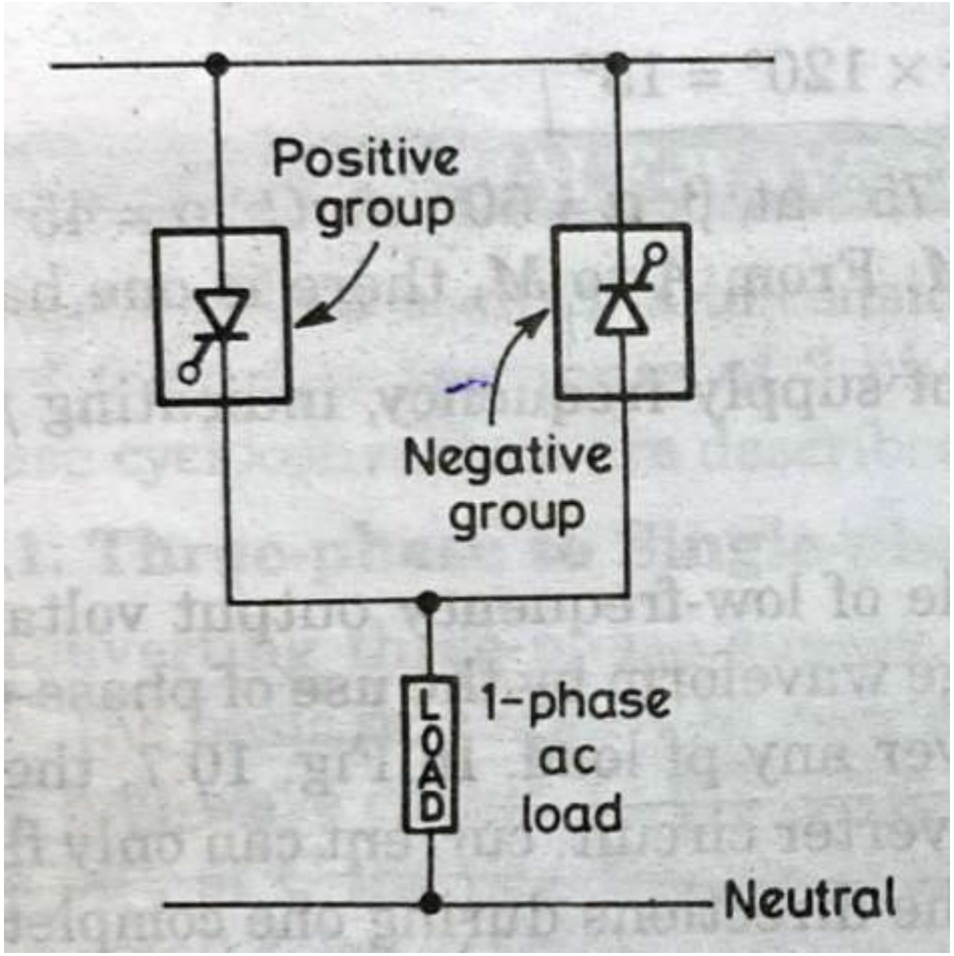
Output of Step Up Cycloconverter



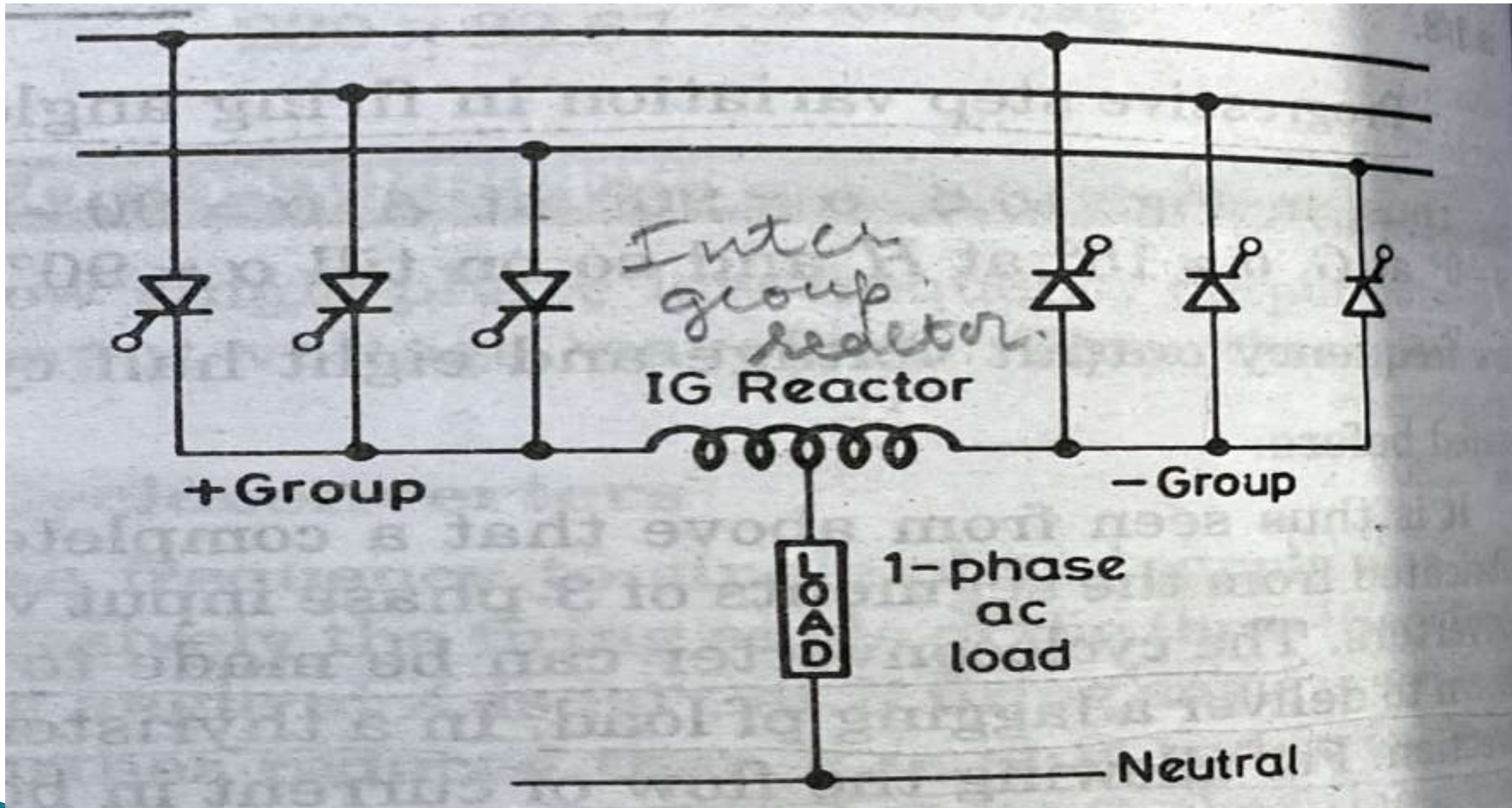
Principle of Operation



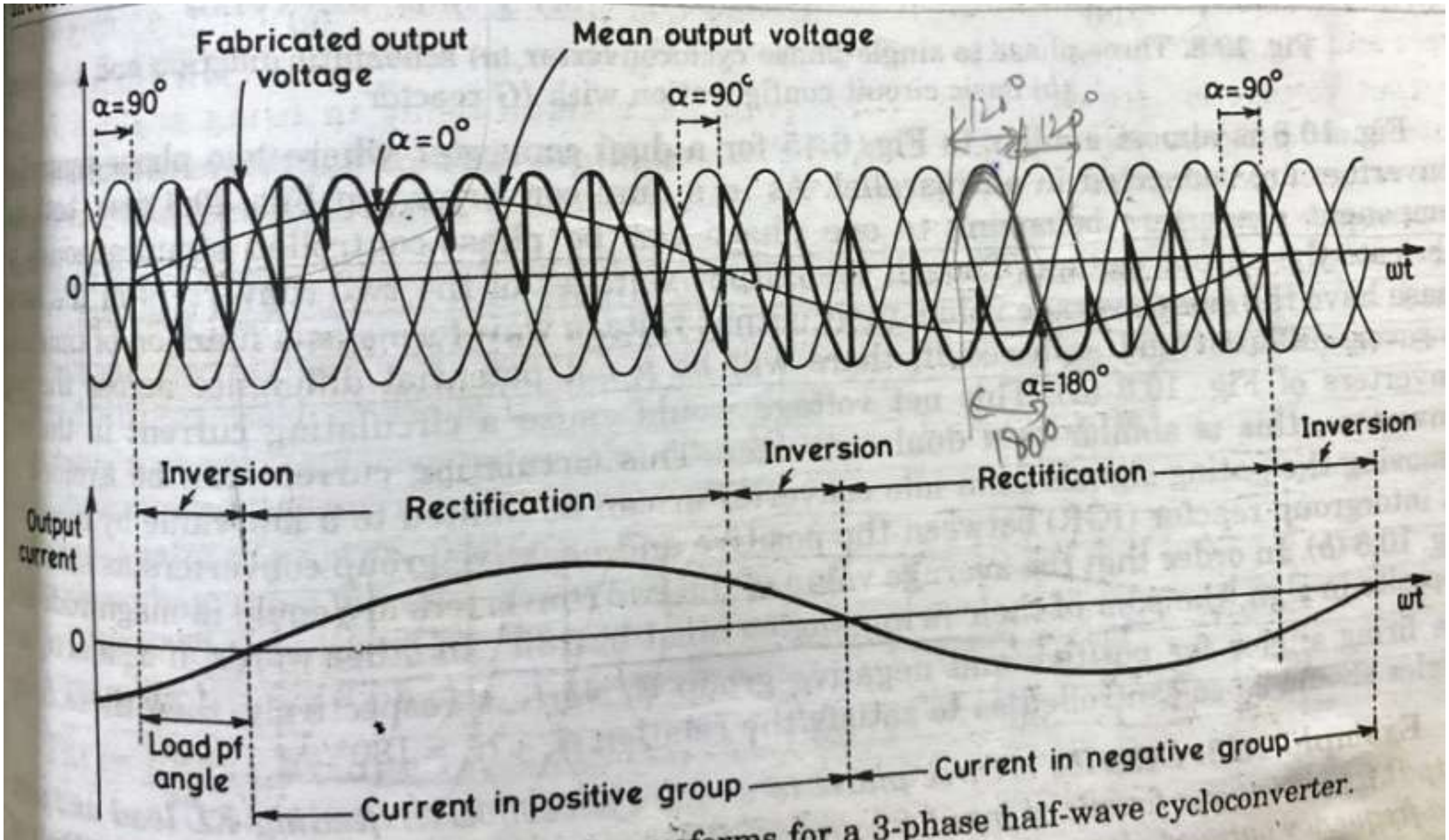
3 Phase, Half Wave Cycloconverter



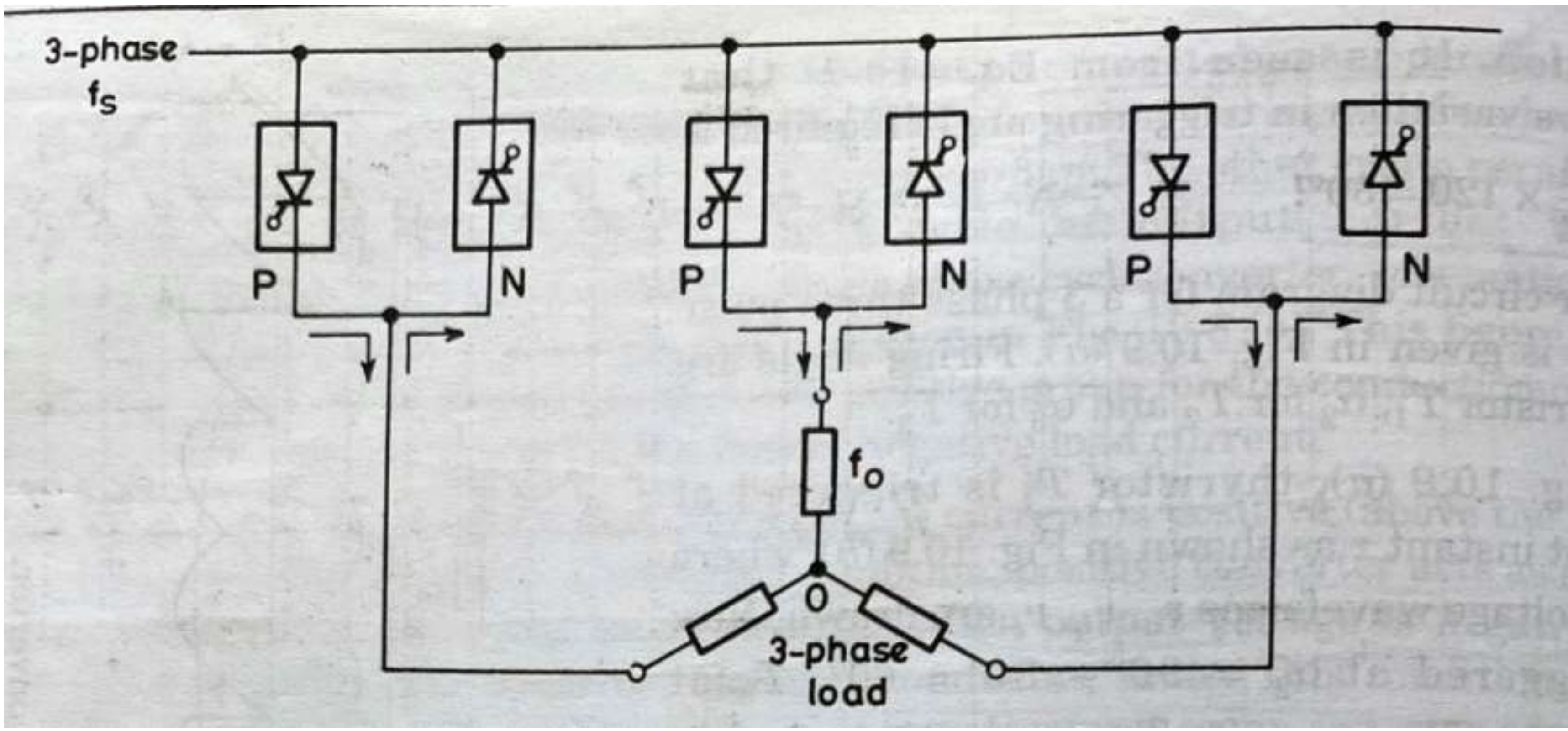
3 Phase, Half Wave Cycloconverter



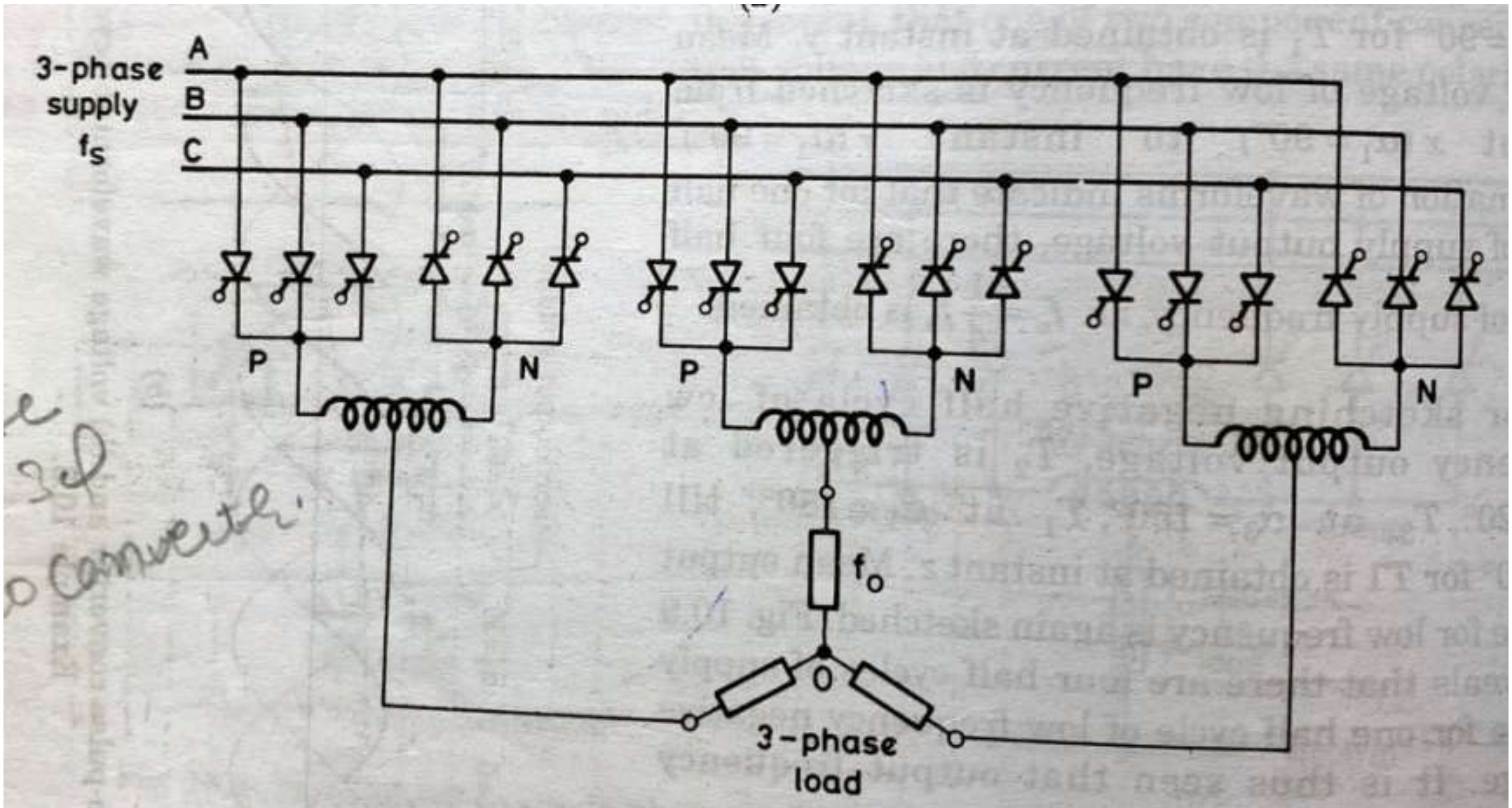
3 Phase, Half Wave Cycloconverter



3 Phase, Full Wave Cycloconverter



3 Phase, Full Wave Cycloconverter



3 Phase, Full Wave Cycloconverter