Welcome to LAB Protocol

VNR VJIET-PES Lab-EEE

VNR VJIET – VNR LAB Protocol

Power Electronics and Simulation Laboratory

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Power Electronics

✓ Power electronics is the technology associated with the efficient conversion, control and conditioning of electric power by static means from its available input form into desired electrical output form.

✓ The goal of power electronics is to control the flow of energy from an electrical source to an electrical load with high efficiency, high availability, high reliability, small size, light weight and low cost.

✓ The Power conversion systems according to the type of the input and output power are :

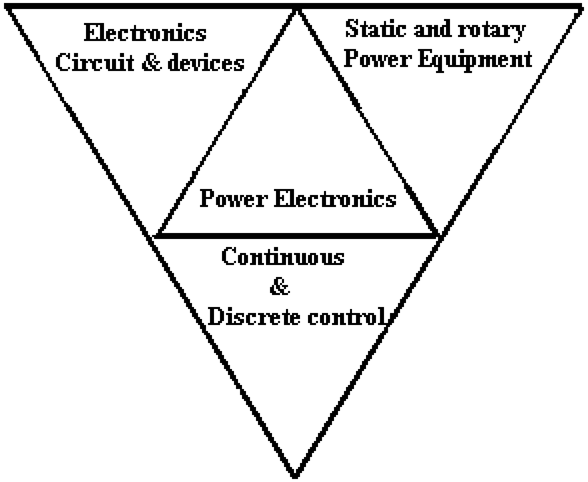
AC to DC Conversion

DC to AC Conversion

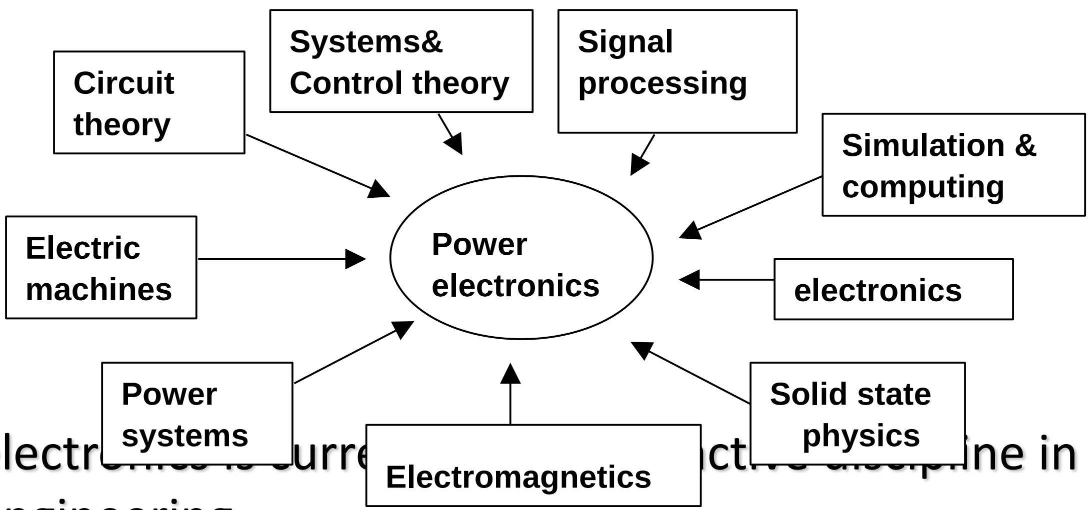
DC to DC Conversion

AC to AC Conversion

The Interdisciplinary Nature



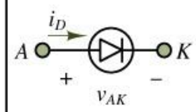
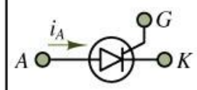
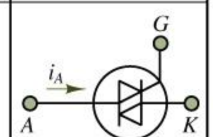
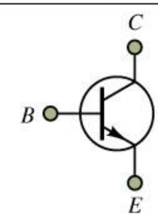
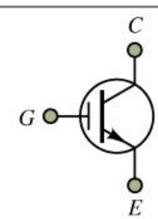
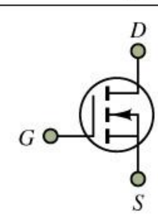
Relation with multiple disciplines



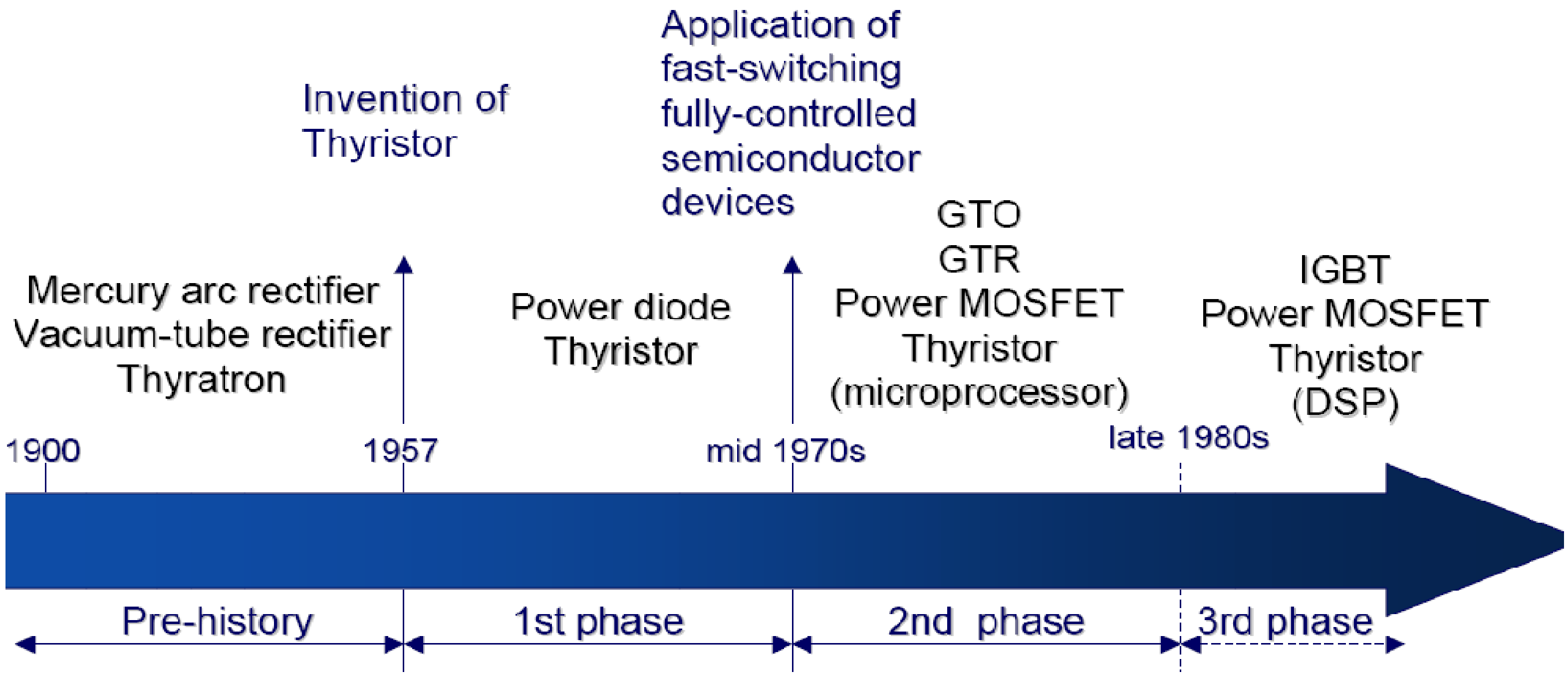
Power electr[illegible] curre[illegible] ct[illegible] ine in electric power engineering.

Classification of Power Electronic Devices

The following is taken from Principles and Applications of Electrical Engineering by G. Rizzoni, McGraw Hill

Device	Device symbol
Diode	
Thyristor	
Gate turnoff thyristor (GTO)	
Triac	
npn BJT	
IGBT	
n-channel MOSFET	

The Evolution of Power electronics



The power electronics revolution has gained momentum since the late 1980s

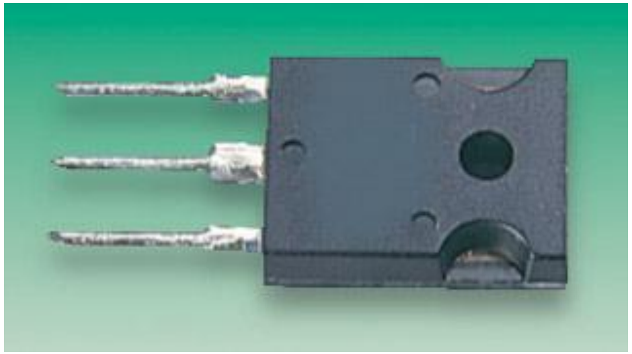
Power Electronic Devices

Vacuum tube

Thyratron

The Evolution of Power electronics

Thyristor (SCR), GTO, Triac



Power MOSFET, IGBT

Comparison between different commonly used Thyristors

- Line Commutated Thyristors available up to 6000V, 4500A.
- Ex: Converter grade (line commutated) SCR.
- V / I rating: 5KV / 5000A
- Max. Frequency: 60Hz.
- Switching time: 100 to 400μsec.
- On state resistance: 0.45mΩ.

- Example of Inverter Grade Thyristor Ratings
- V / I rating: 4500V / 3000A.
- Max. Frequency: 20KHz.
- Switching time: 20 to 100μsec.
- On state resistance: 0.5mΩ.

Ratings of MOSFET & IGBT

- MOSFET V / I rating 700V, 3.3A.
- Max. Frequency: Over 500kHz.
- Switching time around (Ton) 1μsec.
- On state resistance: 3.6Ω.

- IGBT V / I rating 1200V, 3A.
- Max. Frequency: Over 500kHz.
- Switching time around (Ton) 1.2μsec.
- On state resistance: 1.78Ω.

Power Electric Circuits

Circuit type	Essential features
Voltage regulators	Regulate a DC supply to a fixed voltage output
Power amplifiers	Large-signal amplification of voltages and currents
Switches	Electronic switches (e.g., transistor switches)
Diode rectifier	Converts fixed AC voltage (single- or multiphase) to fixed DC voltage
AC-DC converter (controlled rectifier)	Converts fixed AC voltage (single- or multiphase) to variable DC voltage
AC-AC converter (AC voltage controller)	Converts fixed AC voltage to variable AC voltage (single- or multiphase)
DC-DC converter (chopper)	Converts fixed DC voltage to variable DC voltage
DC-AC converter (inverter)	Converts fixed DC voltage to variable AC voltage (single- or multiphase)

Scope of Power Electronics

Power Level (Watts)	*System*
0.1-10	• Battery-operated equipment • Flashes/strobes
10-100	• Satellite power systems • Typical offline flyback supply
100 – 1kW	• Computer power supply • Blender
1 – 10 kW	• Hot tub
10 – 100 kW	• Electric car • Eddy current braking
100 kW –1 MW	• Bus • micro-SMES
1 MW – 10 MW	• SMES
10 MW – 100 MW	• Magnetic aircraft launch • Big locomotives
100 MW – 1 GW	• Power plant
> 1 GW	• Sandy Pond substation (2.2 GW)

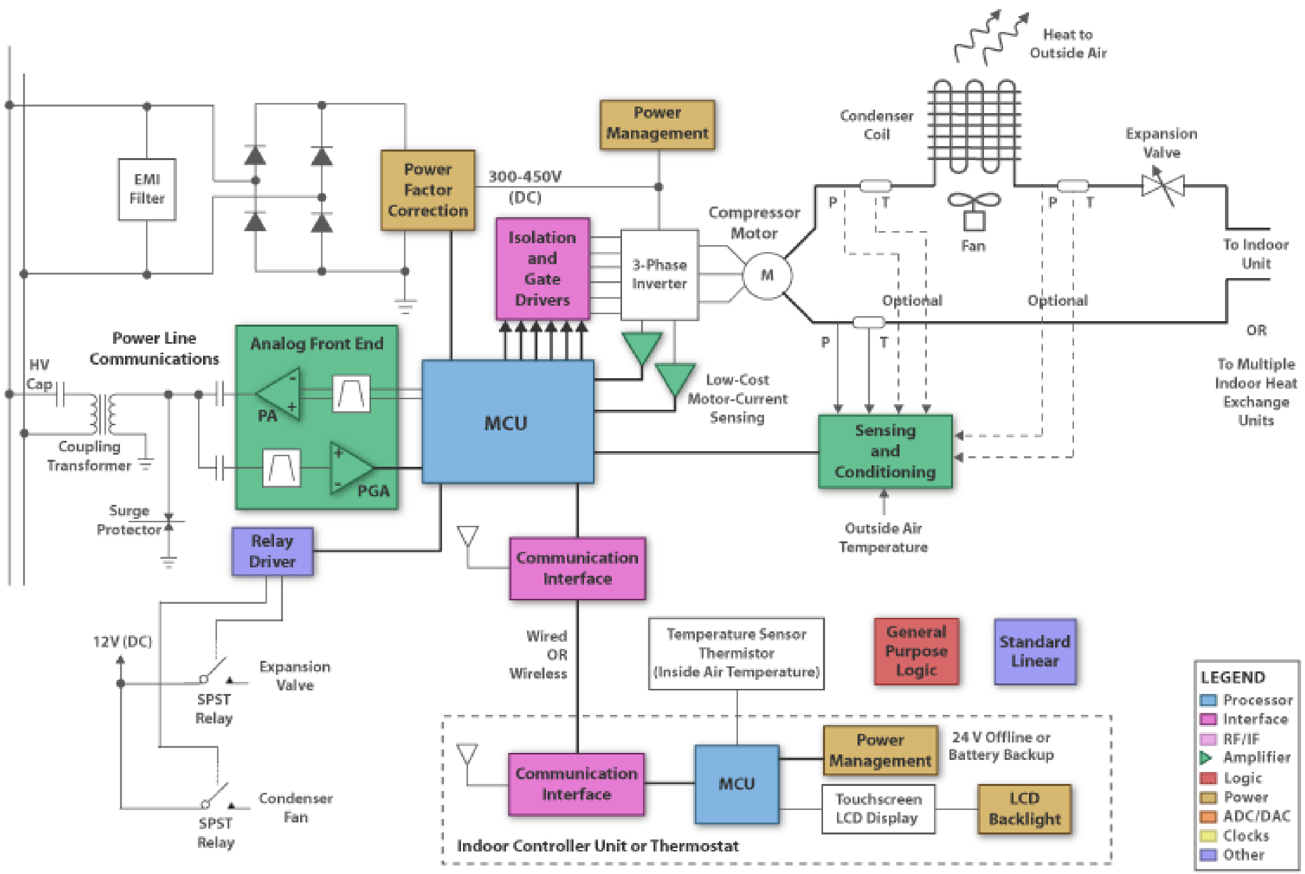
Applications

- ✓ Commercial: Air Conditioners, Central Refrigeration, UPS, Elevators, Emergency Lamps, Heating Systems.
- ✓ Domestic: Cooking Equipments, Lightning & heating systems, Air conditioners, Refrigerators, Freezers, Personal Computers, washing machines.
- ✓ Telecommunications: Mobile Battery Chargers,Modular DC Supplies .
- ✓ Transportation: Electric vehicles, MAGLEV Trains, Battery operated vehicles, ship power systems, Air craft power system, Trains & locomotives.
- ✓ Industrial: Motor drives, Electrolysis, Induction heating, Welding, Arc furnaces, ovens.

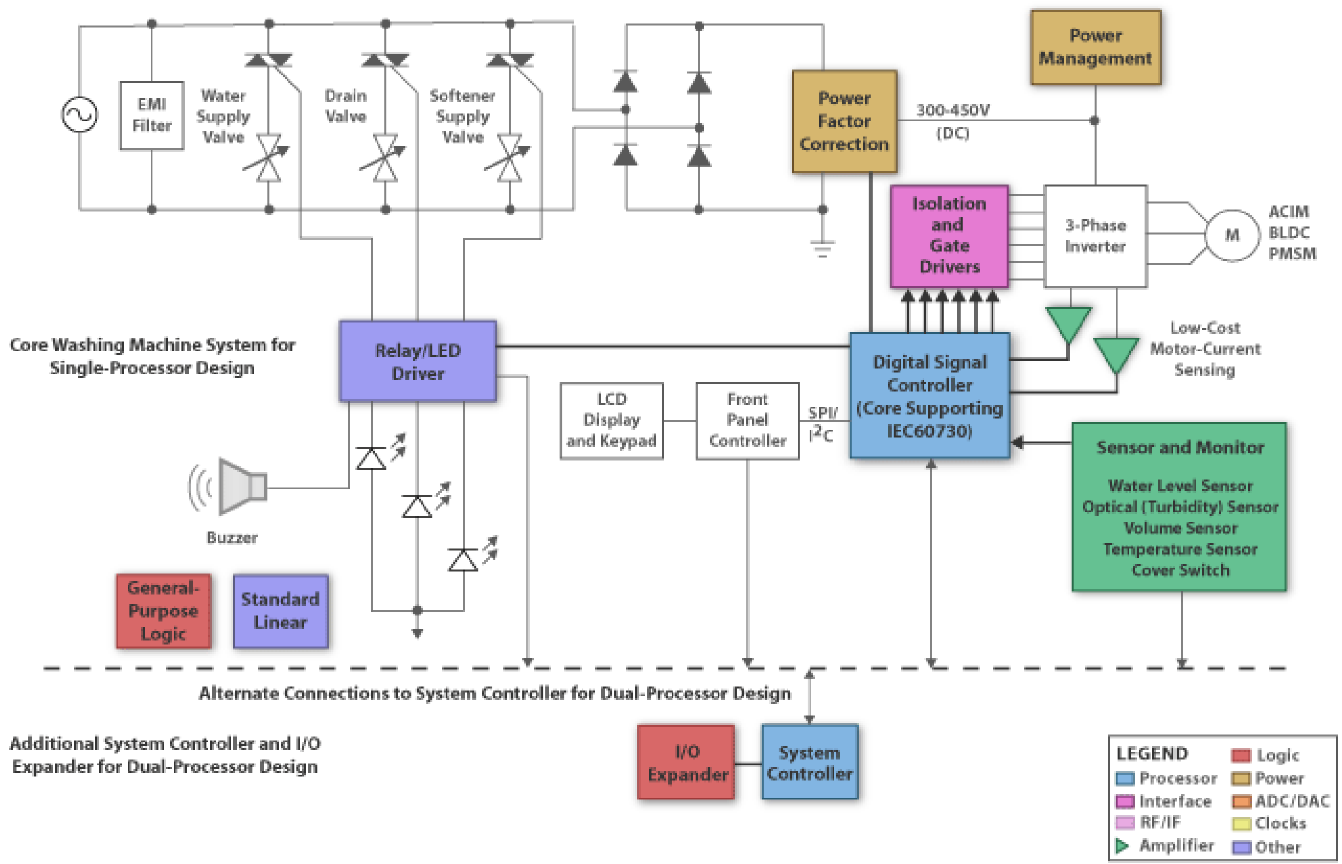
Applications

- ✓ Utility Systems: HVDC, FACTS devices like TCR,TCSC, STATCOM, UPFC, UPQC, Power Quality Control, Reactive power compensation .
- ✓ Renewable Energy Sources: Variable Speed Technology, Active and reactive power control, power conditioning.
- ✓ Military & Aerospace: Unmanned Aerial Vehicles, Unmanned ground vehicles, manned aircraft & spacecraft.

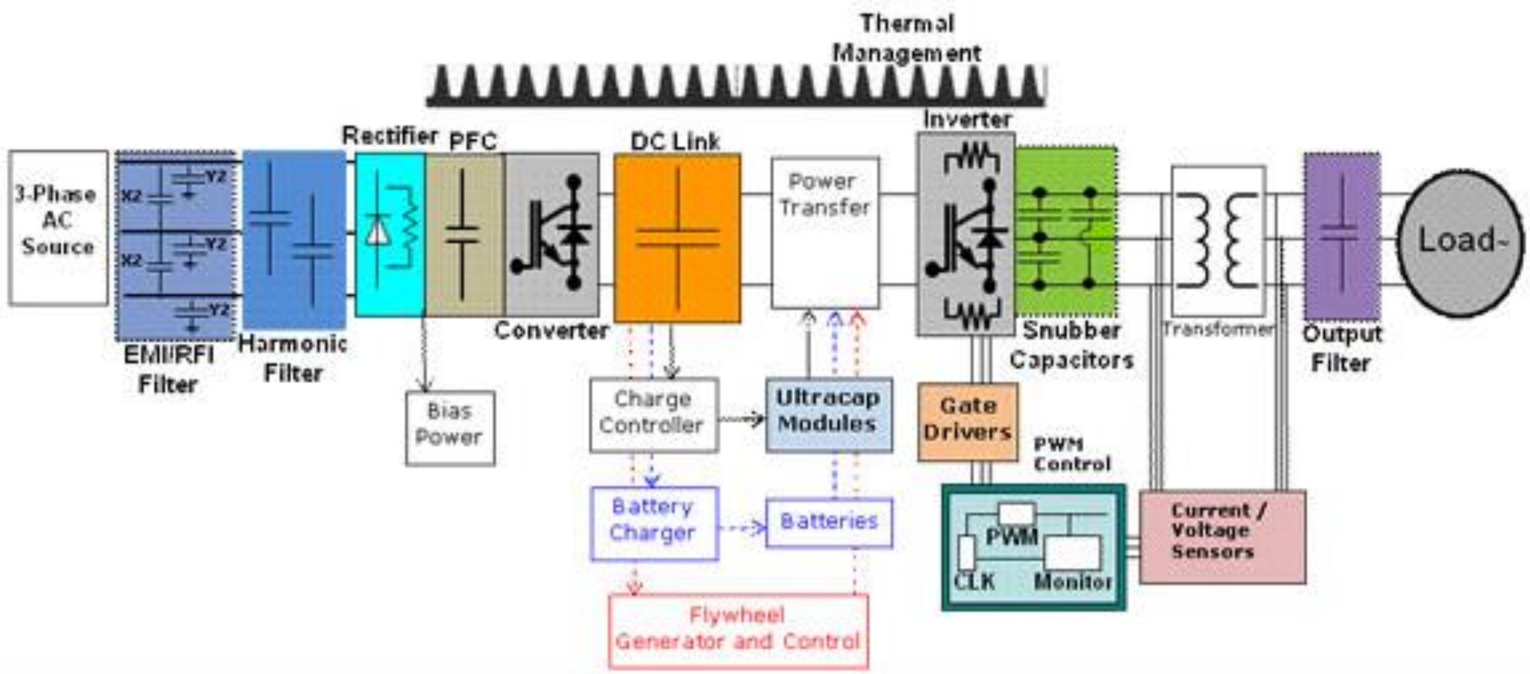
Inverter Controlled Air Conditioners



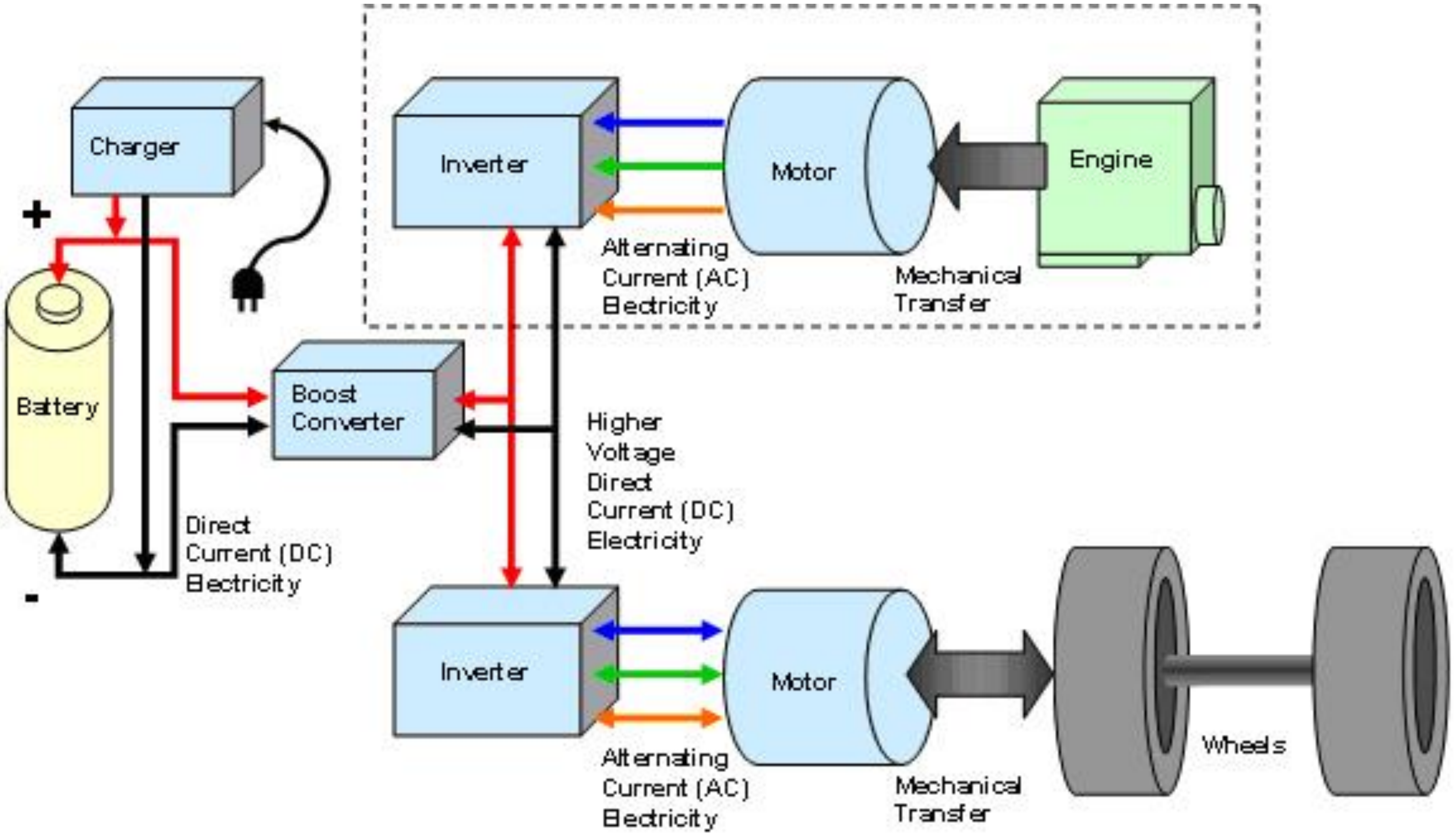
Inverter Controlled Washing Machine



Uninterruptible Power Supply

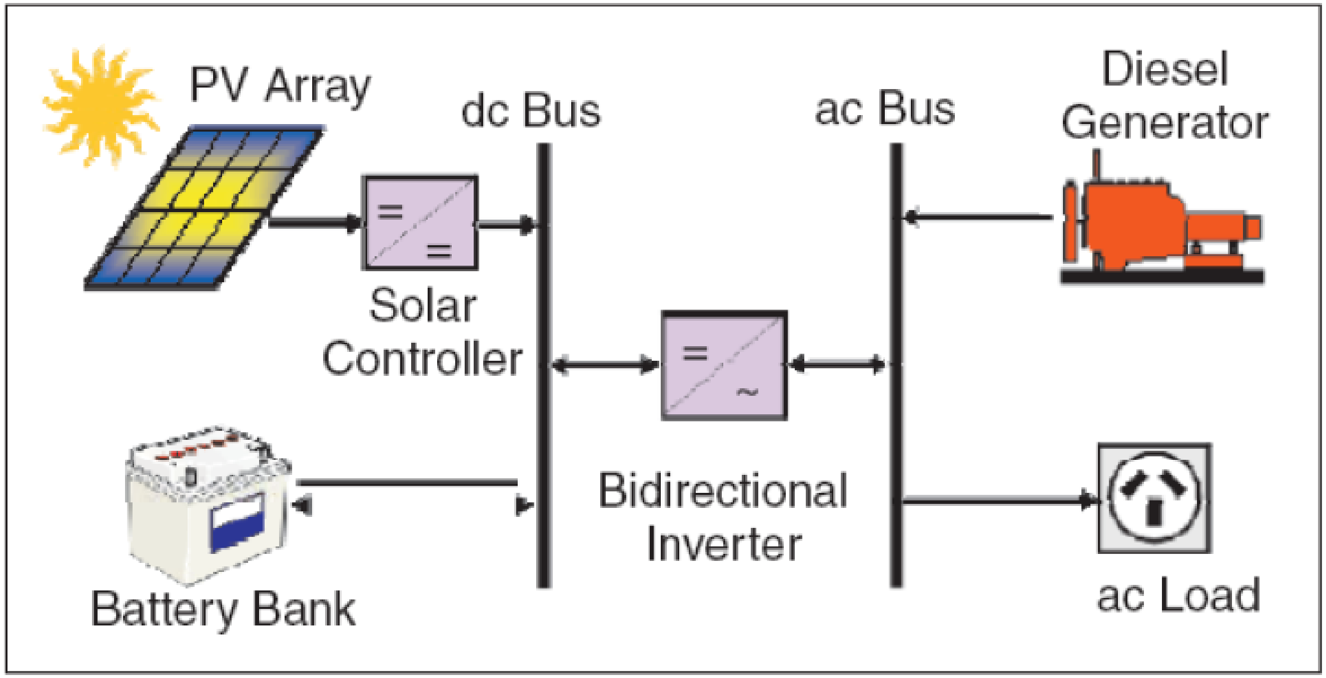


Hybrid Vehicle

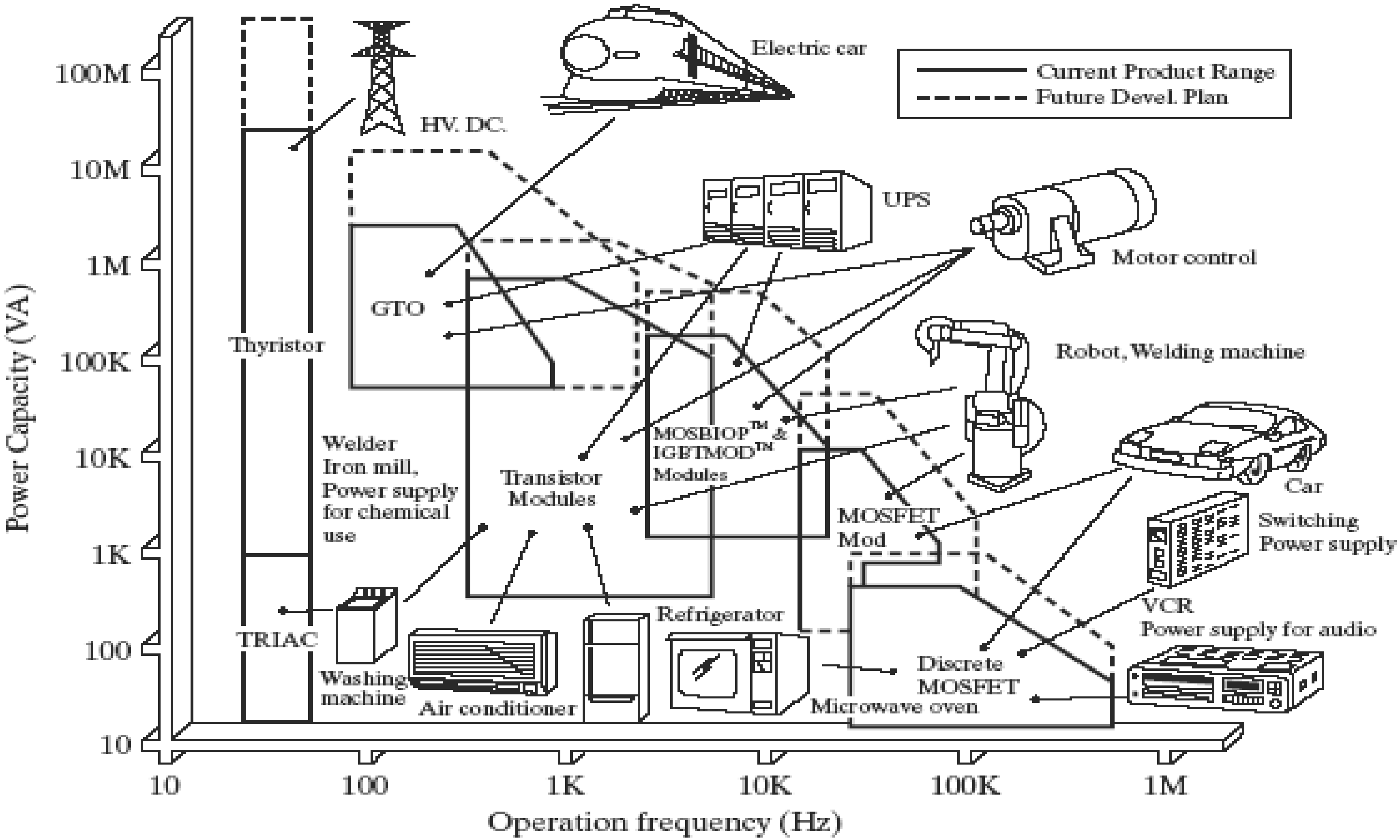


Renewable energy sources

Photovoltaics



Applications of Power Devices



FPGAs and Plug-in Hybrid Vehicles
Power Electronics, FPGA, Applications

- **FPGAs and Plug-in Hybrid Vehicles**
- **Sep.15, 2010 in Motor Control IP, Technology, Power Electronics, FPGA, Applications**

Electrical Circuits and Simulation Lab

Part A : **HARDWARE EXPERIMENTS**

Part B : ***SIMULATION***

PART A

1. Study of Characteristics of SCR, MOSFET & IGBT
2. Study of UJT gate firing circuit for SCR
3. Single Phase AC Voltage Controller with R and RLLoads
4. Single Phase fully controlled bridge converter with R and RL loads
5 Single Phase Cyclo-converter with R and RL loads
6. Single Phase half controlled converter with R load
7. Three Phase half controlled bridge converter with R-load
8. Single Phase Bridge inverter with R and RL loads
9. Study of buck converter
10. Study of boost converter

PART-B

1. (a)Simulation of single-phase Half wave converter using R and RL loads

(b)Simulation of single-phase full converter usingR, RL and RLE loads

(c)Simulation of single-phase Semi converter usingR, RL and RLE loads

2. (a)Simulation of Single-phase AC voltage controller using R and RL loads

(b)Simulation of Single phase Cyclo-converter withR and RL-loads

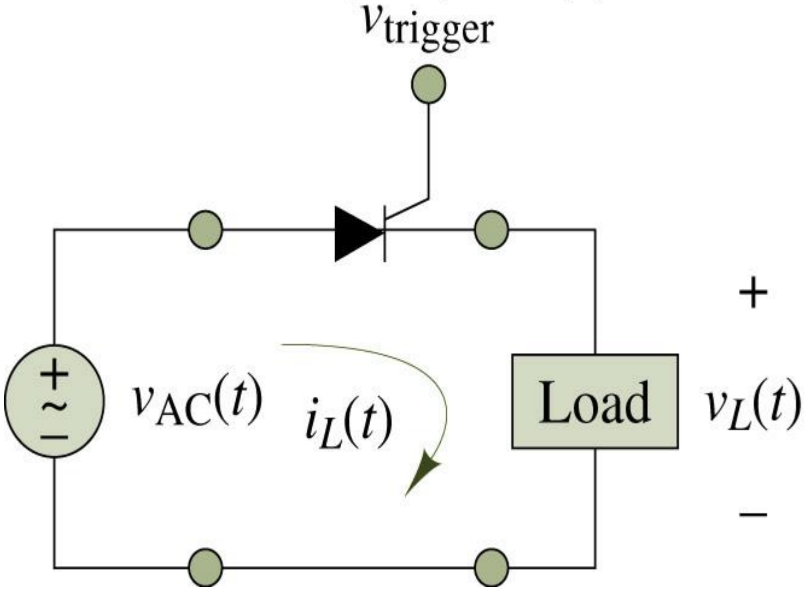
3. Simulation of Buck chopper

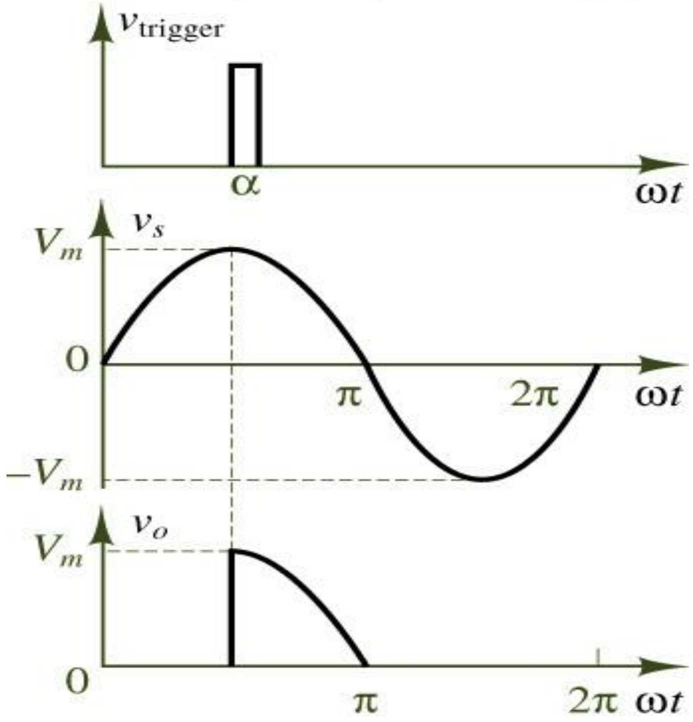
4. Simulation of single phase Inverter with PWM control.

5.Simulation of three phase fully controlled converter with R and RL loads, with and without freewheeling diode. Observation of waveforms for Continuous and Discontinuous modes of operation.

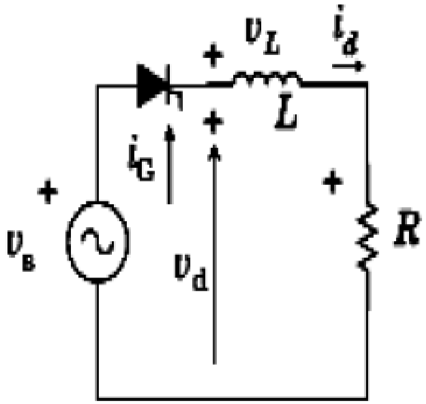
6. Study of PWM technique

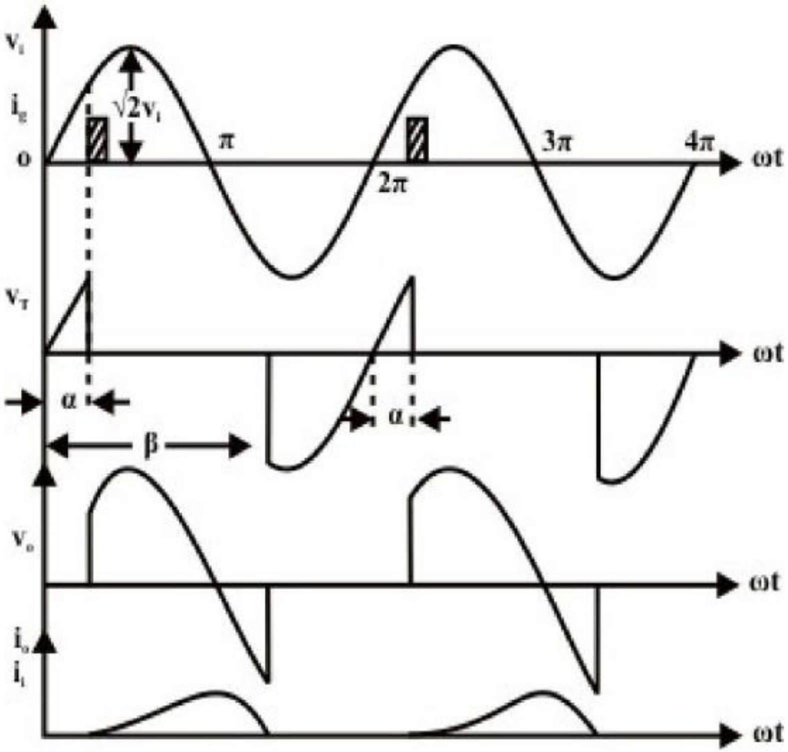
Single Phase Half Controlled Converter





Single Phase Half Controlled Converter with RL-Load





Circuit Operation

- At $\omega t = 0$ when the input supply voltage becomes positive the thyristor T becomes forward biased. However, unlike a diode, it does not turn ON till a gate pulse is applied at $\omega t = \alpha$. During the period $0 < \omega t \leq \alpha$, the thyristor blocks the supply voltage and the load voltage remains zero as shown.
- Consequently, no load current flows during this interval.
- As soon as a gate pulse is applied to the thyristor at $\omega t = \alpha$ it turns ON. The voltage across the thyristor collapses to almost zero and the full supply voltage appears across the load. From this point onwards the load voltage follows the supply voltage. The load being purely resistive the load current i_o is proportional to the load voltage.

Circuit Operation

- At $\omega t = \pi$ as the supply voltage passes through the negative going zero crossing the load voltage and hence the load current becomes zero and tries to reverse direction. In the process the thyristor undergoes reverse recovery and starts blocking the negative supply voltage.

- Therefore, the load voltage and the load current remains clamped at zero till the thyristor is fired again at $\omega t = 2\pi + \alpha$. The same process repeats there after.

From above discussion one can write.

For $\alpha \le \omega t \le \beta$

$$v_0 = v_i = \sqrt{2}\, V_i \sin\omega t$$

$v_0 = 0$ otherwise

Therefore

$$V_{OAV} = \frac{1}{2\pi}\int_0^{2\pi} v_0 \, d\omega t$$

$$= \frac{1}{2\pi}\int_\alpha^{\beta} \sqrt{2}\, V_i \sin\omega t \, d\omega t$$

$$= \frac{V_i}{\sqrt{2}\pi}(\cos\alpha - \cos\beta)$$

$$V_{ORMS} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} v_0^2 \, d\omega t}$$

$$= \sqrt{\frac{1}{2\pi}\int_\alpha^{\beta} 2v_i^2 \sin^2\omega t \, d\omega t}$$

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

$$I_{OAV} = \frac{V_{OAV}}{R} = \frac{V_i}{\sqrt{2}\pi R}(\cos\alpha - \cos\beta)$$

Applications of Half Controlled Converter

- Electric Welding.
- Electroplating of metals.
- Electrorefining of metals.
- Motor speed control.

- Commutation
- Thyristor voltages and currents
- Transformer current

$$U_d = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha}\sqrt{2}U_2 \sin \omega t \mathrm{d}(\omega t) = \frac{2\sqrt{2}}{\pi}U_2 \cos\alpha = 0.9U_2 \cos\alpha$$

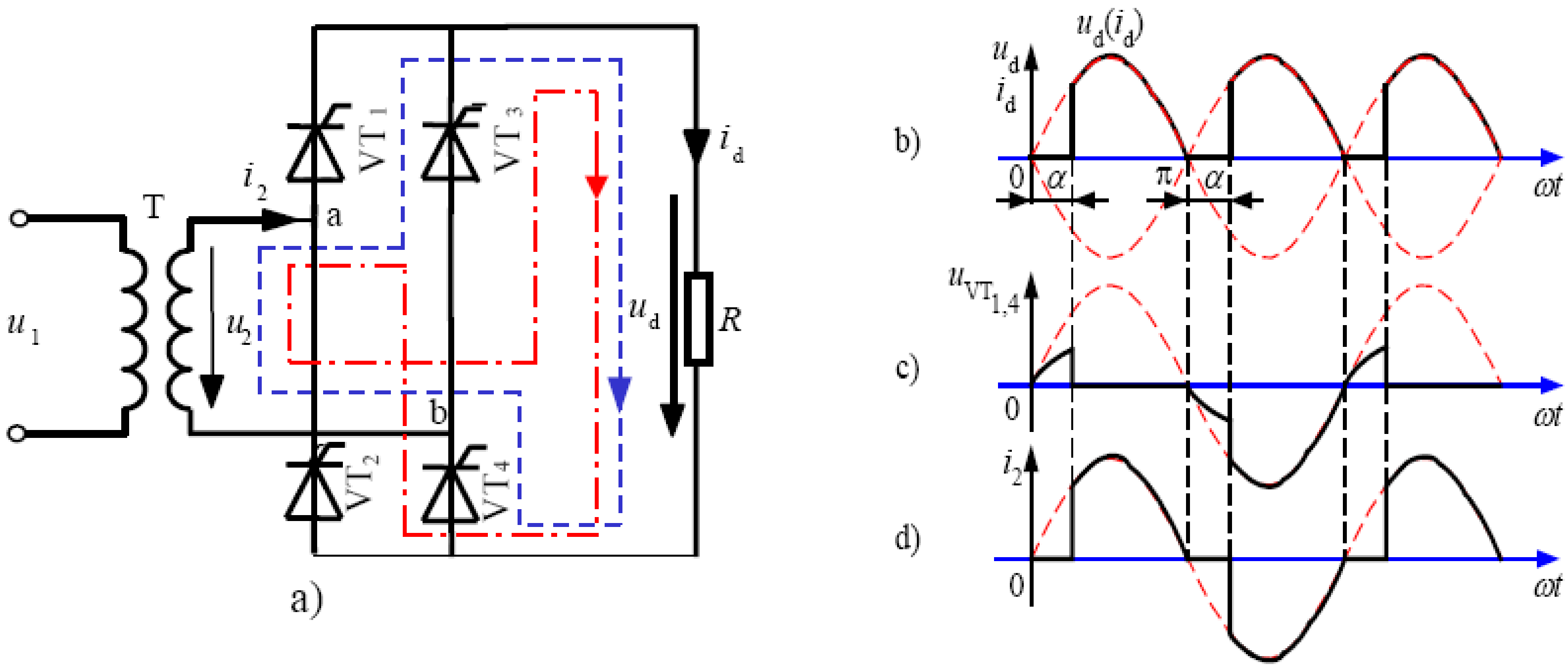
$$I_{dVT} = \frac{1}{2} I_d \qquad I_{VT} = \frac{1}{\sqrt{2}} I_d$$

$$I_2 = I_d$$

$$0 \le \alpha \le \frac{\pi}{2} \qquad \mathbf{\theta = 180°}$$

$$U_{DM} = U_{RM} = \sqrt{2}U_2$$

Single Phase Fully controlled bridge converter with R load.



- Assumption: Ls=0

For thyristor: maximum forward voltage, maximum reverse voltage

Advantages: — 2pulses in one line cycle

— No DC component in the transformer current

- Average output (rectified) voltage

$$U_d = \frac{1}{\pi}\int_{\alpha}^{\pi}\sqrt{2}U_2 \sin\omega t \, d(\omega t) = \frac{2\sqrt{2}U_2}{\pi}\frac{1+\cos\alpha}{2} = 0.9U_2\frac{1+\cos\alpha}{2}$$

- **Average output current**

$$I_d = \frac{U_d}{R} = \frac{2\sqrt{2}U_2}{\pi R}\frac{1+\cos\alpha}{2} = 0.9\frac{U_2}{R}\frac{1+\cos\alpha}{2}$$

- **For thyristor**

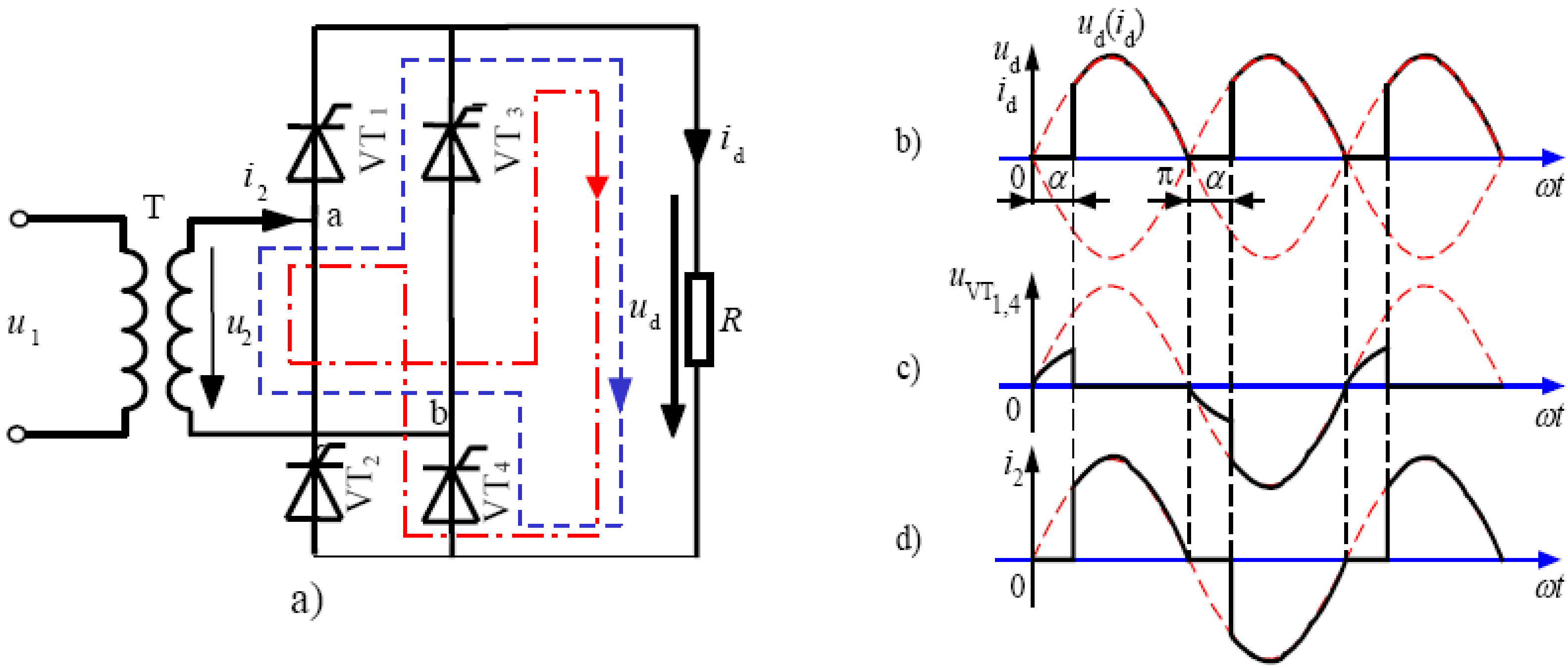
$$I_{dVT} = \frac{1}{2}I_d = 0.45\frac{U_2}{R}\frac{1+\cos\alpha}{2}$$

$$I_{VT} = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\pi}\left(\frac{\sqrt{2}U_2}{R}\sin\omega t\right)^2 d(\omega t)} = \frac{U_2}{\sqrt{2}R}\sqrt{\frac{1}{2\pi}\sin 2\alpha + \frac{\pi-\alpha}{\pi}}$$

- **For transformer** $I = I_2 = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi}\left(\frac{\sqrt{2}U_2}{R}\sin\omega t\right)^2 d(\omega t)} = \frac{U_2}{R}\sqrt{\frac{1}{2\pi}\sin 2\alpha + \frac{\pi-\alpha}{\pi}}$

$$0 \le \alpha \le \pi$$

Single Phase Fully controlled bridge converter with R load.



- ➢Assumption: Ls=0

For thyristor: maximum forward voltage, maximum reverse voltage

Advantages: — 2pulses in one line cycle

— No DC component in the transformer current

- Commutation
- Thyristor voltages and currents
- Transformer current

$$U_d = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} \sqrt{2}U_2 \sin \omega t \mathrm{d}(\omega t) = \frac{2\sqrt{2}}{\pi} U_2 \cos\alpha = 0.9U_2 \cos\alpha$$

$$I_{dVT} = \frac{1}{2} I_d \qquad I_{VT} = \frac{1}{\sqrt{2}} I_d$$

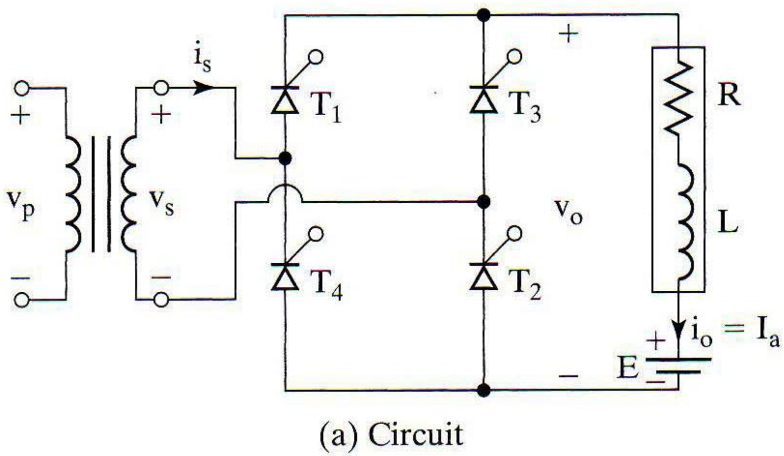
$$I_2 = I_d$$

$$0 \le \alpha \le \frac{\pi}{2} \qquad \theta = 180°$$

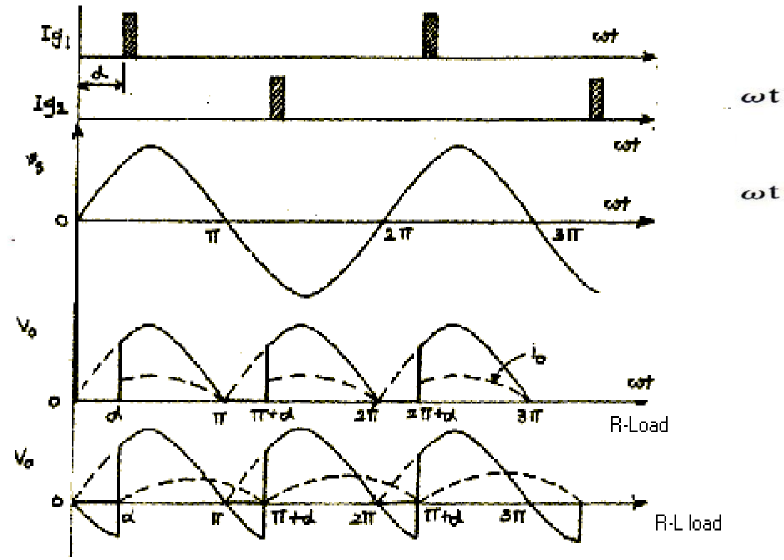
$$U_{DM} = U_{RM} = \sqrt{2}U_2$$

An AC to DC converter circuit can convert AC voltage into a DC voltage. The DC output voltage can be controlled by varying the firing angle of the thyristors. The AC input voltage could be a single phase or three phase.

Single phase, Full wave AC to DC converter



(a) Circuit



The average output voltage can be found from :

$$V_{dc} = \frac{2}{2\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin \omega t \, d(\omega t) = \frac{2V_m}{2\pi}\left[-\cos \omega t\right]_{\alpha}^{\pi+\alpha}$$

$$= \frac{2V_m}{\pi}\cos\alpha$$

- Assumption: α =0° and Ls=0 , so

$$\frac{U_d}{U_{d0}} = \cos\alpha \qquad U_{do} = \frac{1}{\pi}\int_0^{\pi} \sqrt{2}U_2 \cdot \sin\omega t \cdot d(\omega t) = \frac{2\sqrt{2}}{\pi}U_2 = 0.9U_2$$

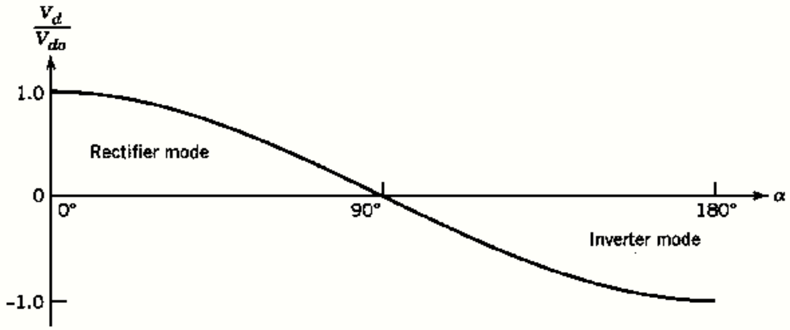
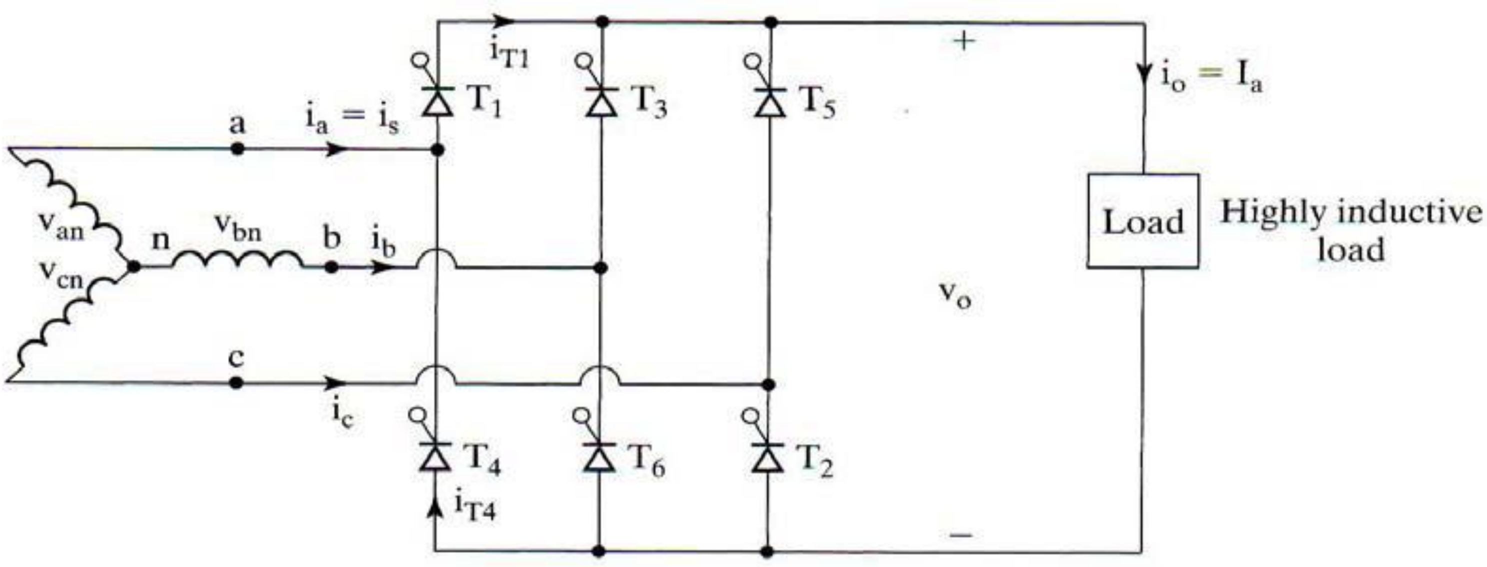


Figure 6-7 Normalized V_d as a function of α.

- Rectifier mode
- Inverter mode

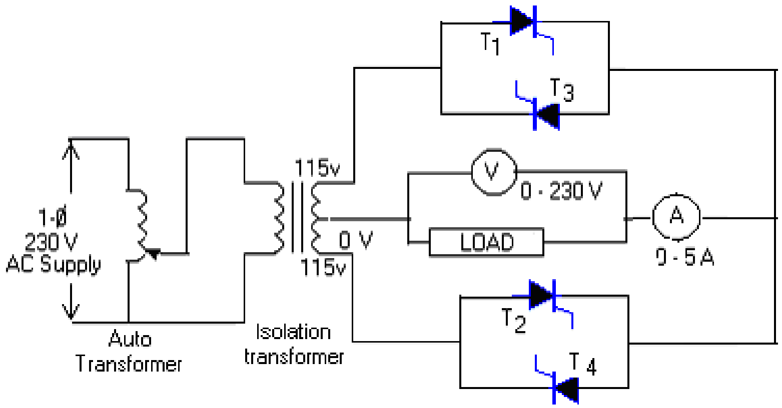
- Average Power: $P = \frac{1}{T}\int_0^T p(t)dt = \frac{1}{T}\int_0^T u_d i_d dt = I_d(\frac{1}{T}\int_0^T u_d dt) = I_d U_d = 0.9U_2 I_d \cos\alpha$

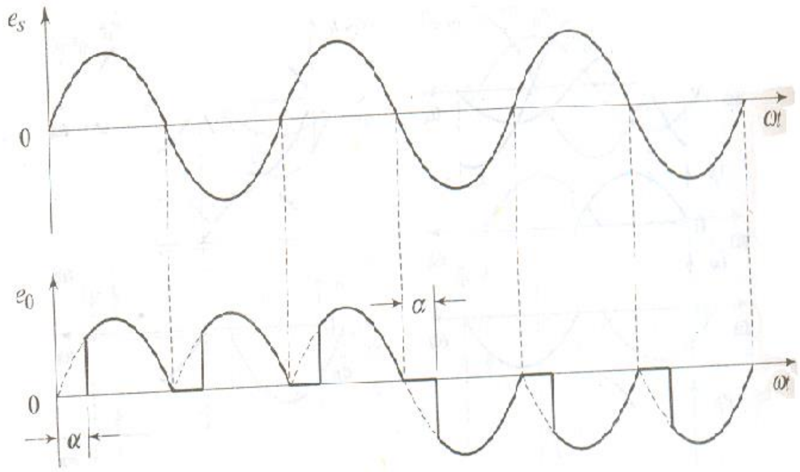
3-phase full wave converter



(a) Circuit

1-phase cycloconverter





AC- Voltage controller with R -Load