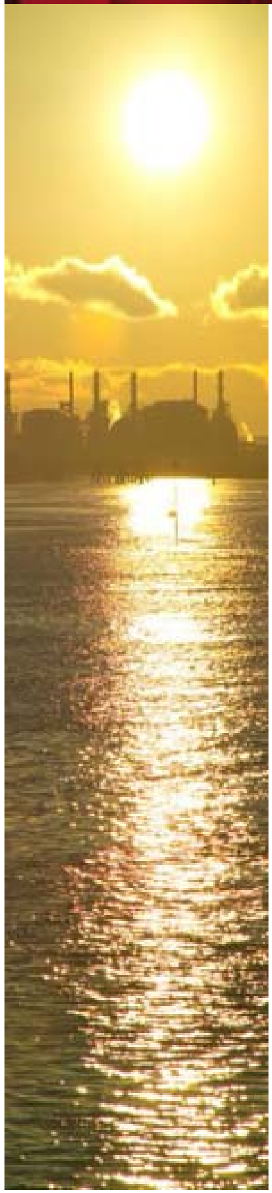
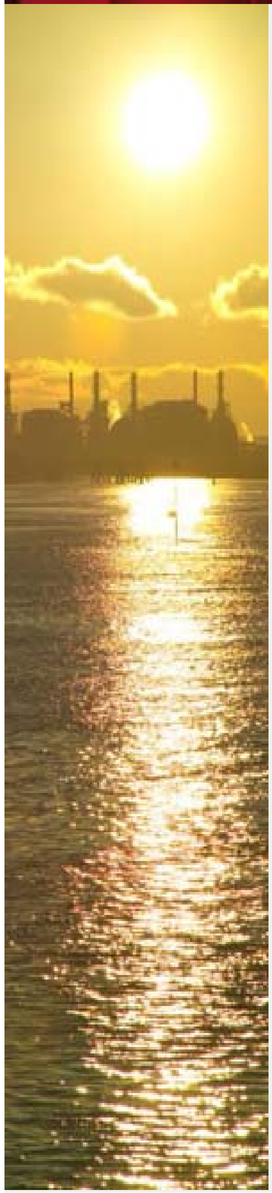


Photovoltaic Systems Engineering

Ali Karimpour
Assistant Professor
Ferdowsi University of Mashhad

Reference for this lecture:
Photovoltaic Systems Engineering Third Edition CRC
Roger Messenger, Jerry Ventre



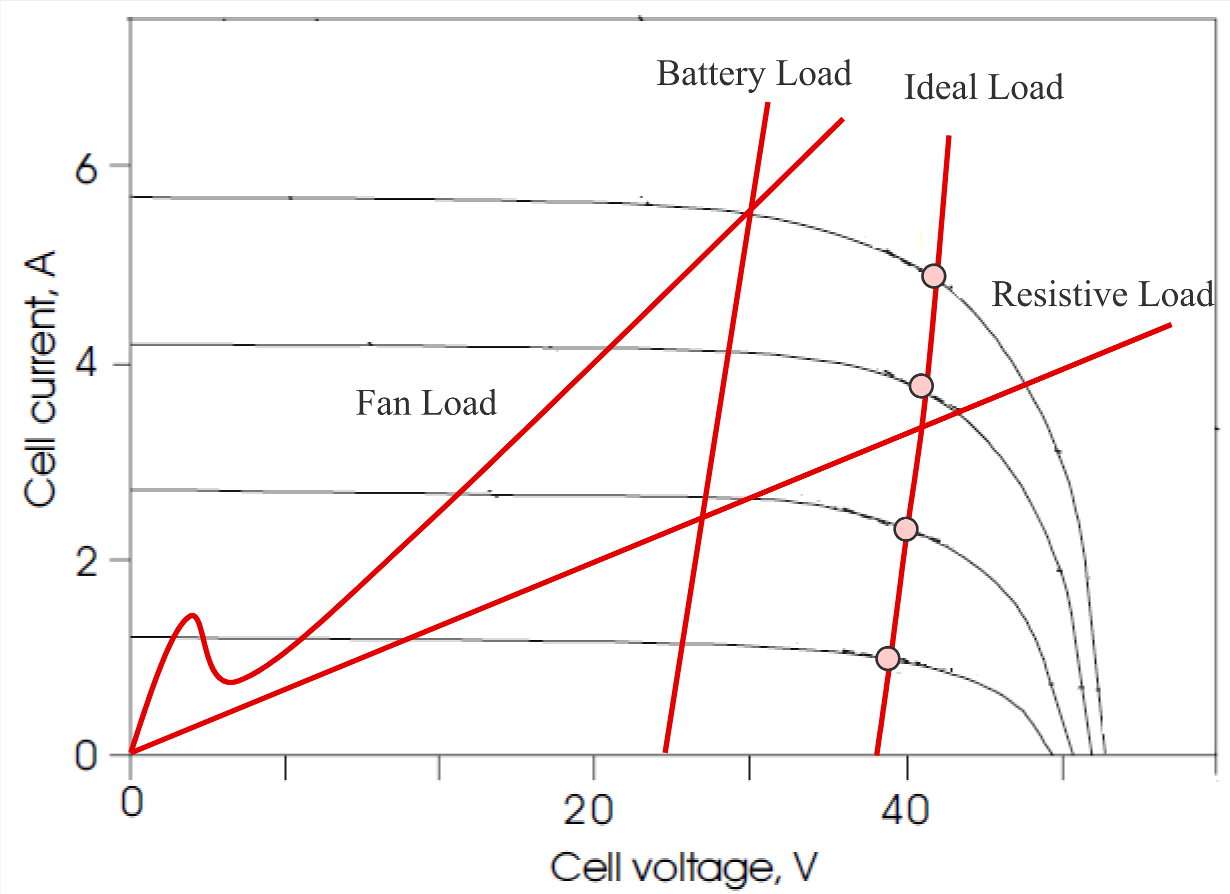
PV System Loads and Electronics

PV System Loads

System Availability

System Electronic Components
- Introduction
- Charge Controllers
- MPPT circuits
- Inverters

V-I characteristic of a PV



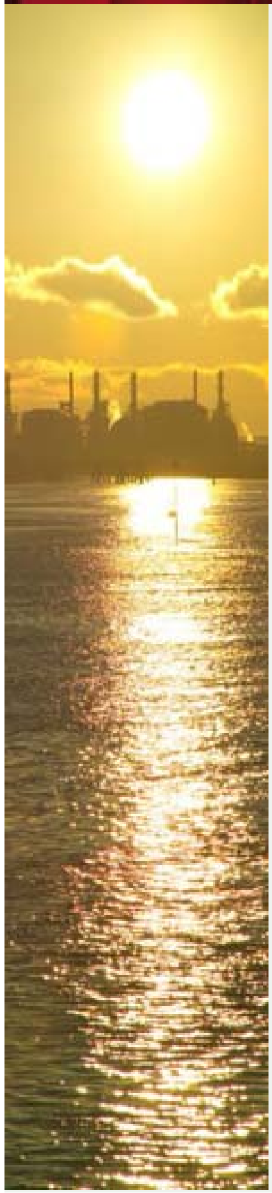
Ideal Load

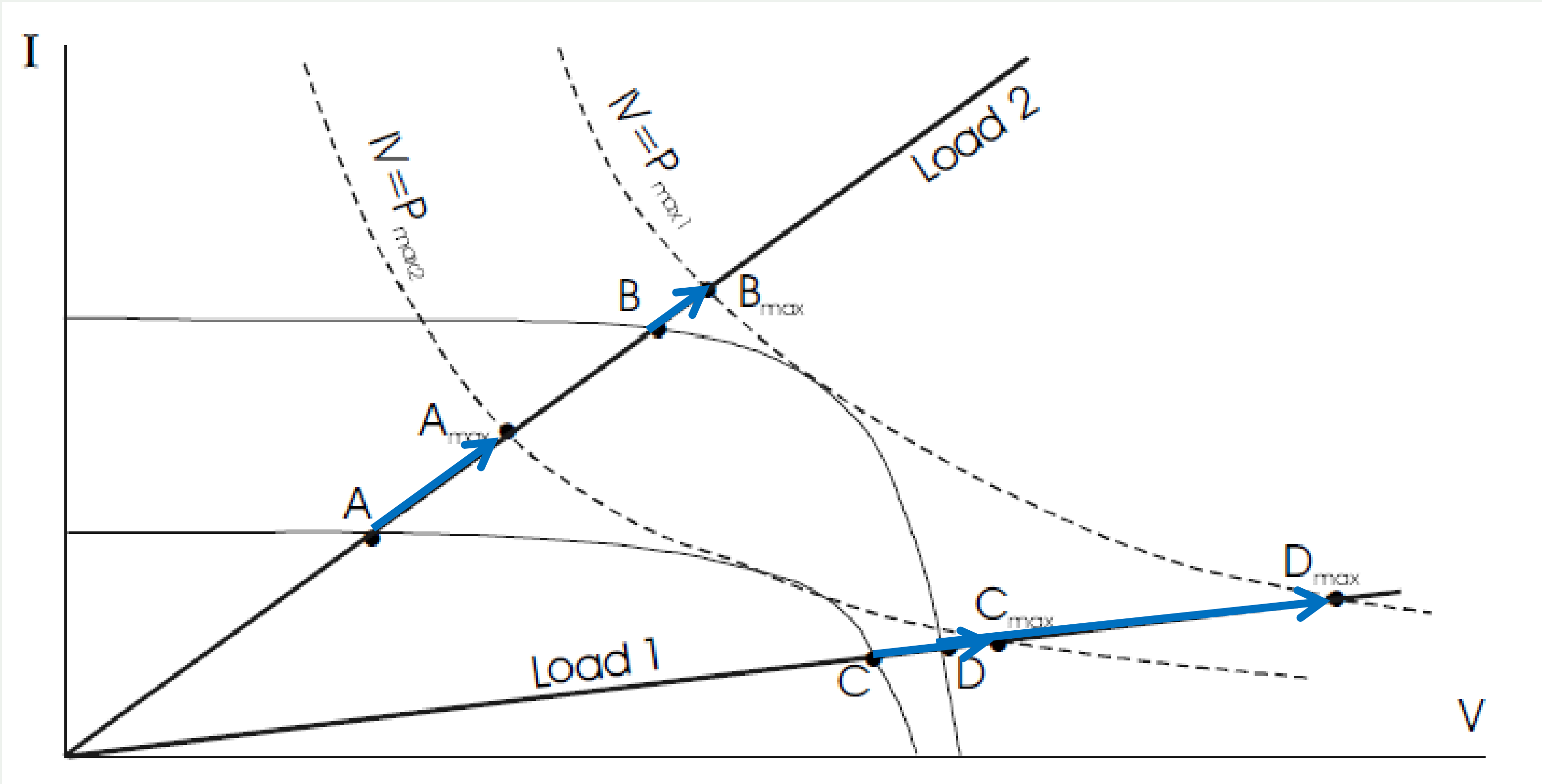
Resistive Load

Battery Load

Fan Load

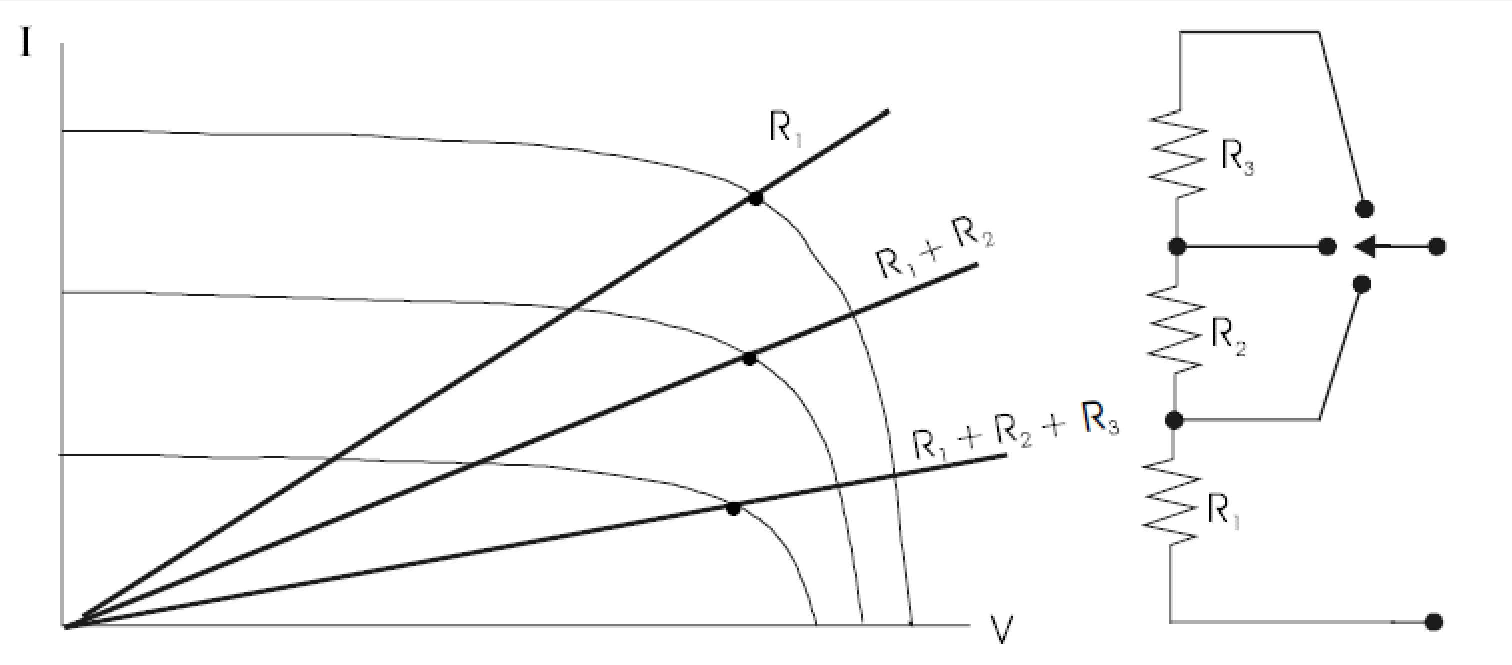
MPPT





But How is it possible?

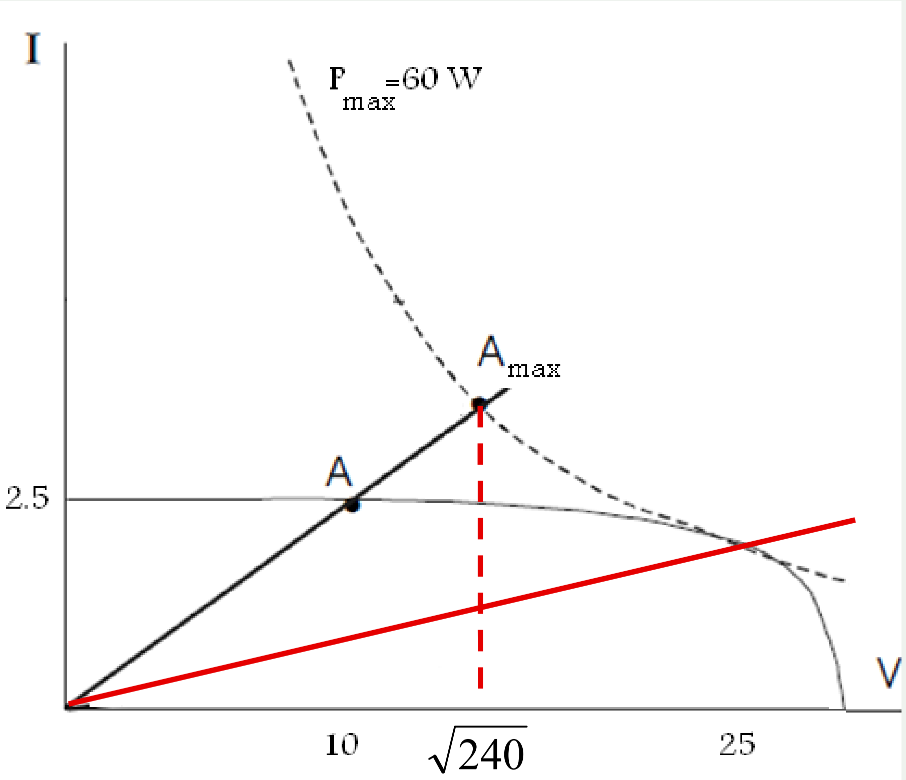
MPPT: Variable resistors

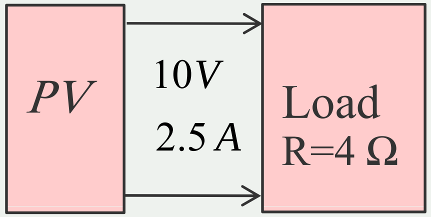


Is it acceptable to pay more initial cost?

Is it acceptable to pay for a MPPT?

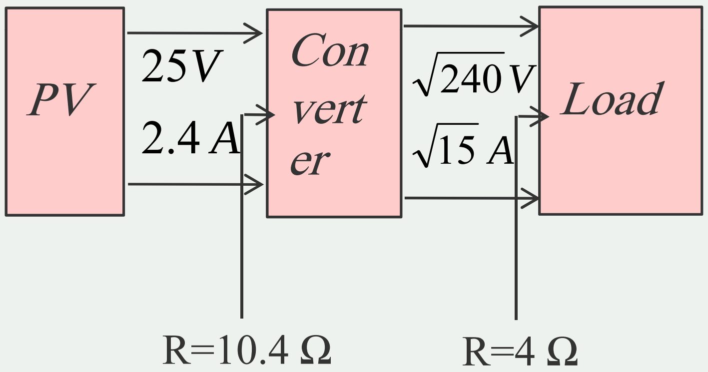
MPPT



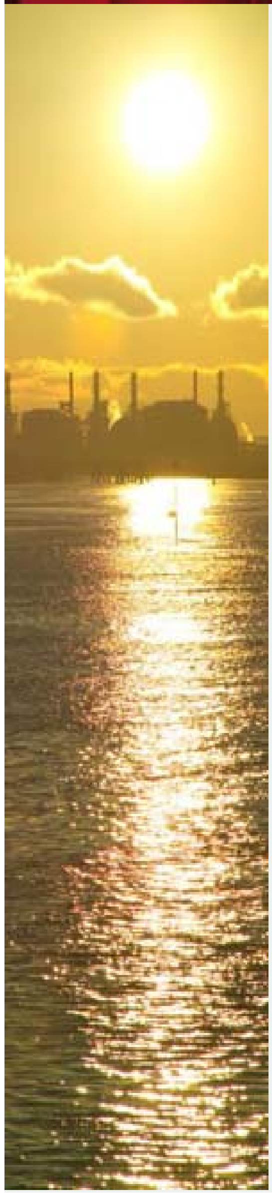


$25W$

$$25W \xrightarrow{?} 60W$$



System Availability



Downtime reasons in conventional power systems:

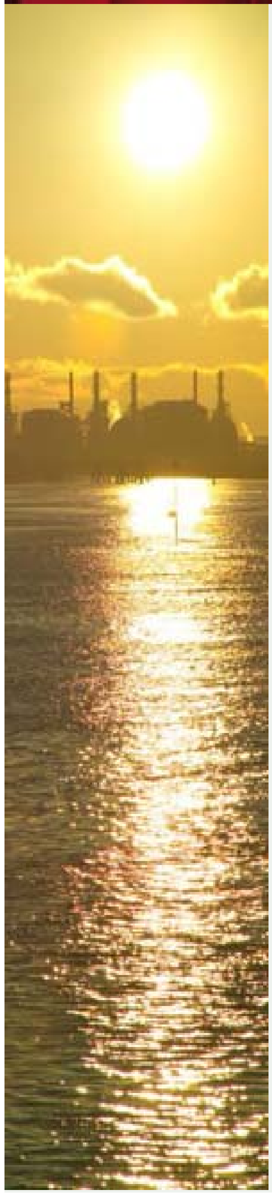
Sc in the system
Failure of a generator
Overload
Failure in the turbine
…….

Downtime reasons in PV systems:

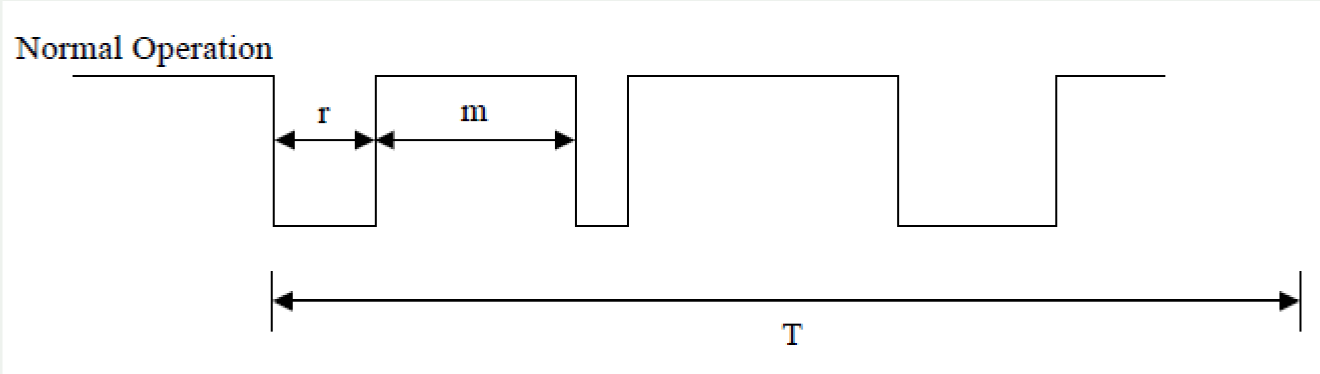
Loose or corroded connections
Battery failure
Controller failure
…….

And also unpredictable cloud cover → Enough battery storage.

System Availability



Availability definition



$$Availability = \frac{\sum m}{T}$$

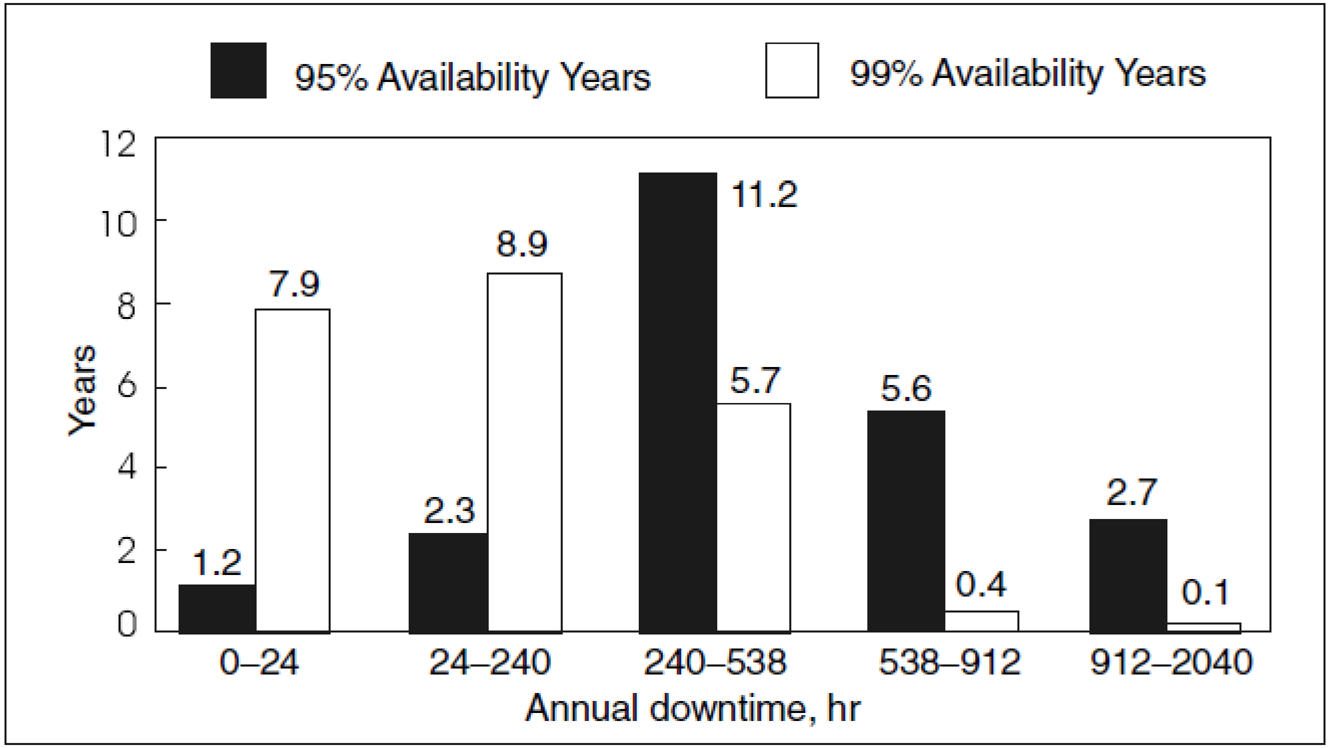
Critical loads: 99% availability

Noncritical loads: 95% availability

System Availability

Critical loads: 99% availability

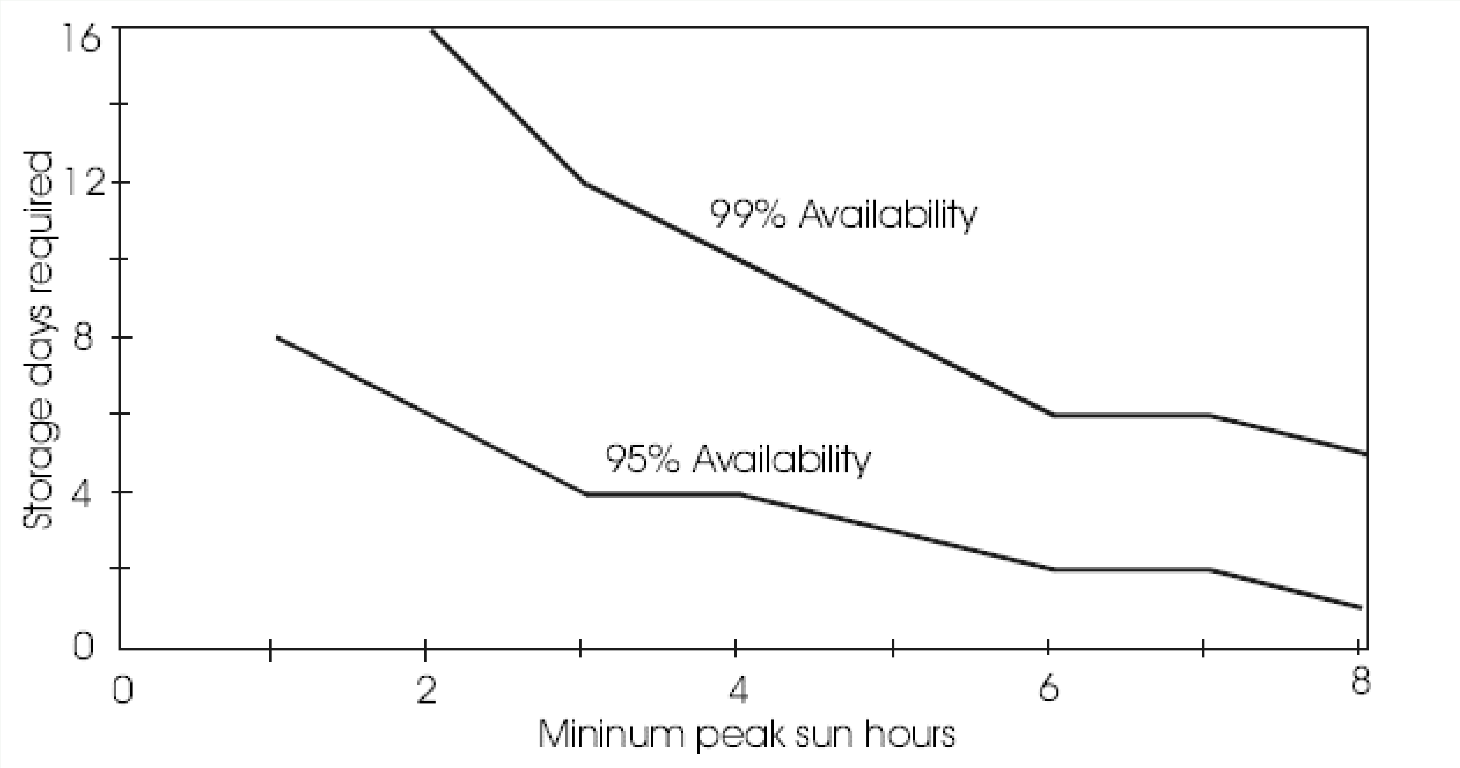
Noncritical loads: 95% availability



Statistical distribution of annual downtime for critical and noncritical PV systems over a 23-year system lifetime.

System Availability

Storage days required for a system

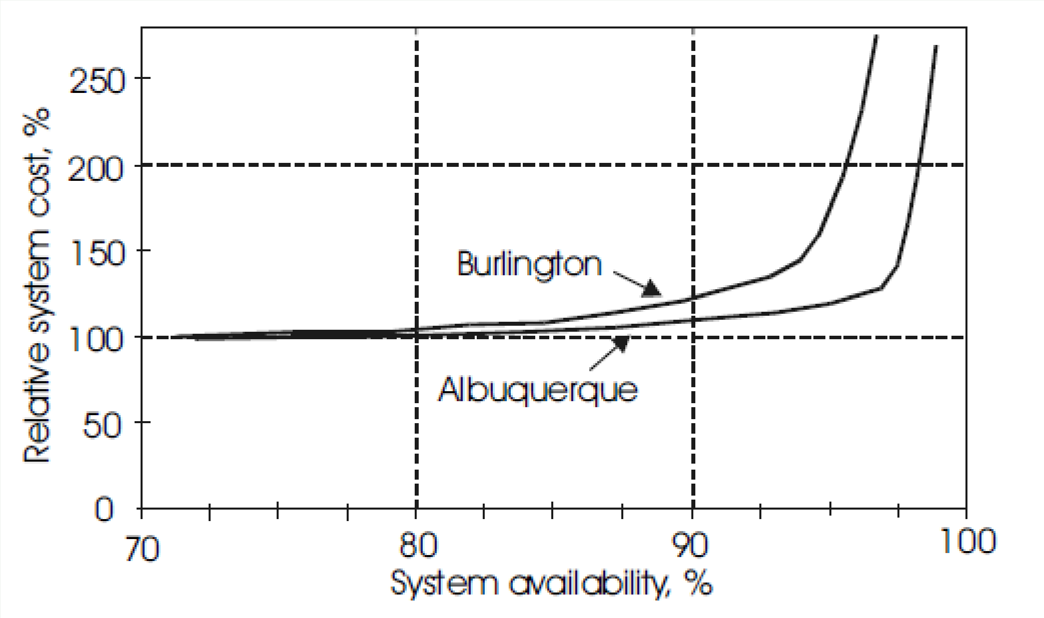


$$D_{crit} = 0.2976T_{\min}^{2} - 4.7262T_{\min} + 24$$

$$D_{non} = 0.1071T_{\min}^{2} - 1.869T_{\min} + 9.4286$$

System Availability

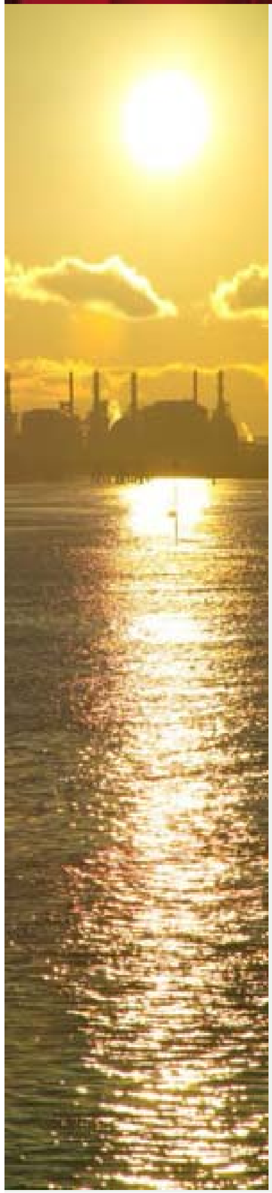
Price of system availability



Burlington latitude is around 44°

Albuquerque latitude is around 35°

System Electronic Components



System Electronic Components

- Introduction
- Charge Controllers
- MPPT circuits
- Inverters

Introduction

Power semiconductor switches
- Diode (uncontrollable)
- Thyristors (Half control)
- Transistors (Full control)
  - Power BJT
  - Power MOSFET
  - IGBT
- Turn on and off by G or B

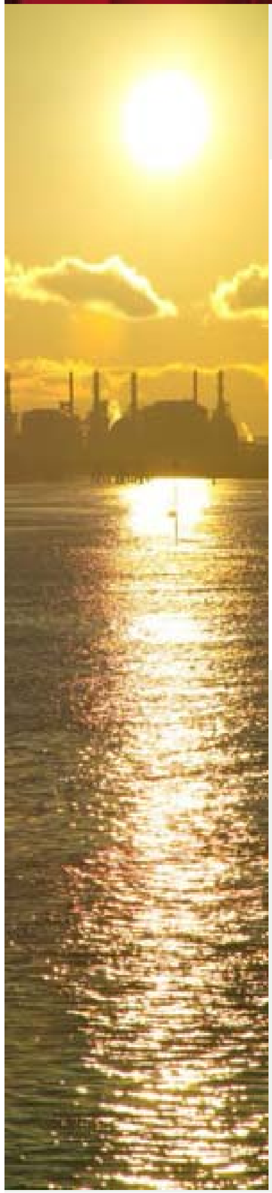
BJT: Bipolar Junction Transistor.

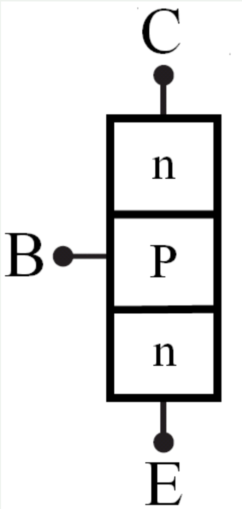
MOSFET: Metal–Oxide Semiconductor Field-Effect Transistor.

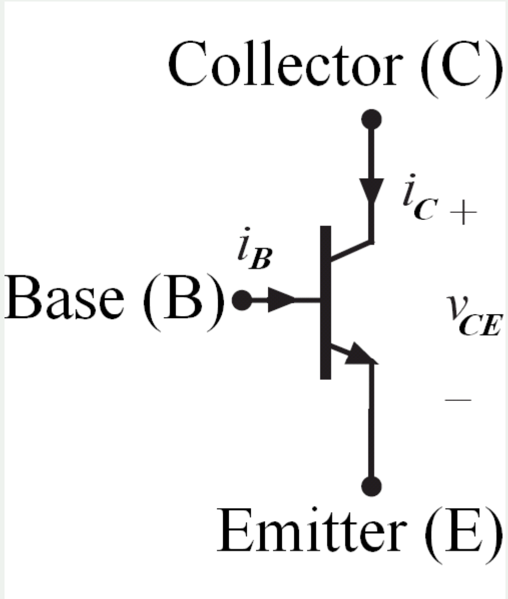
IGBT: Isolated Gate Bipolar Transistor.

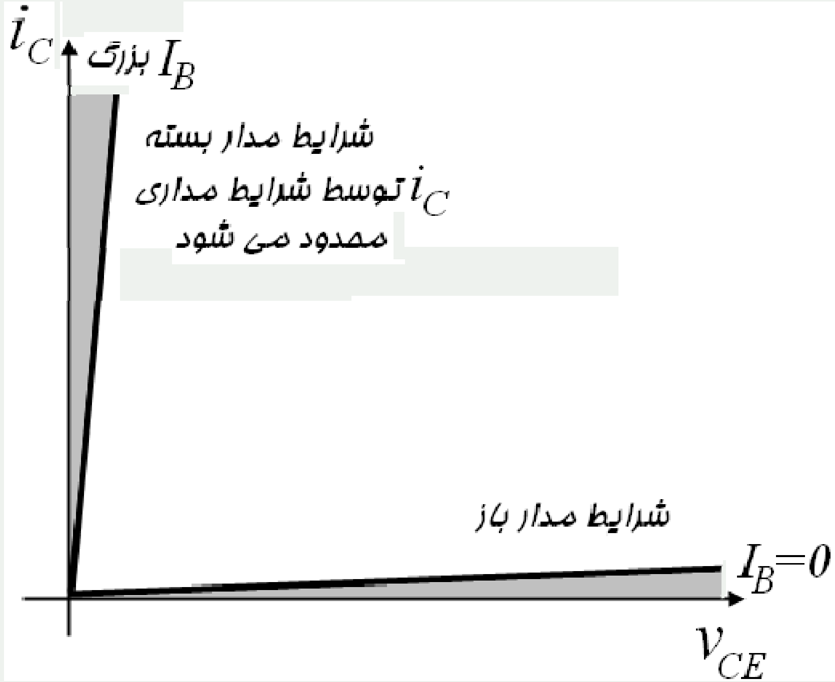
Transistors (Power BJT)

Transistors (Power BJT)

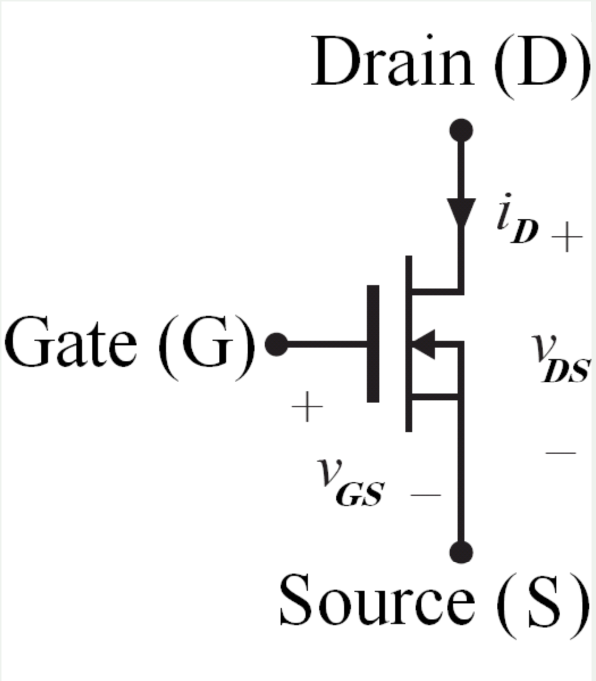


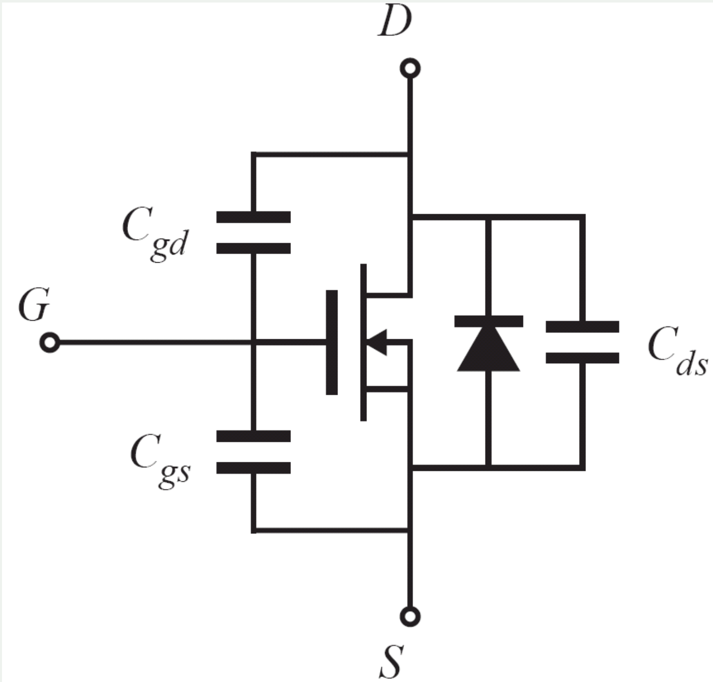






Transistors (Power MOSFET)



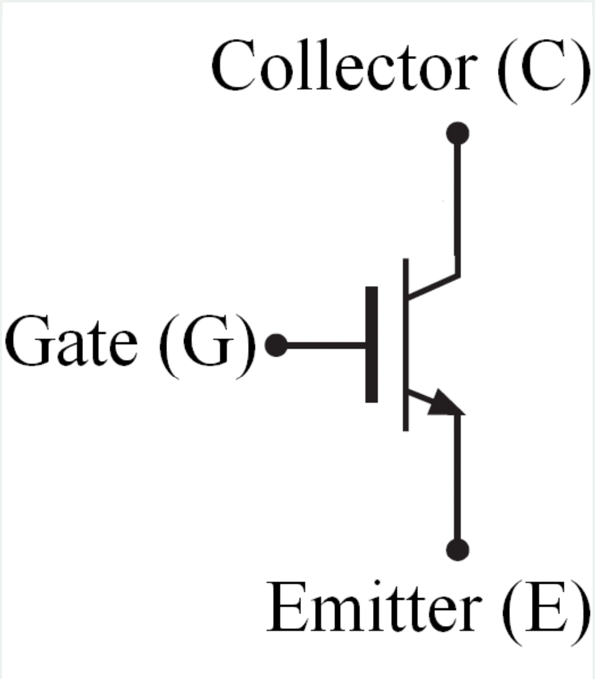


Transistors (Compare BJT and MOSFET)

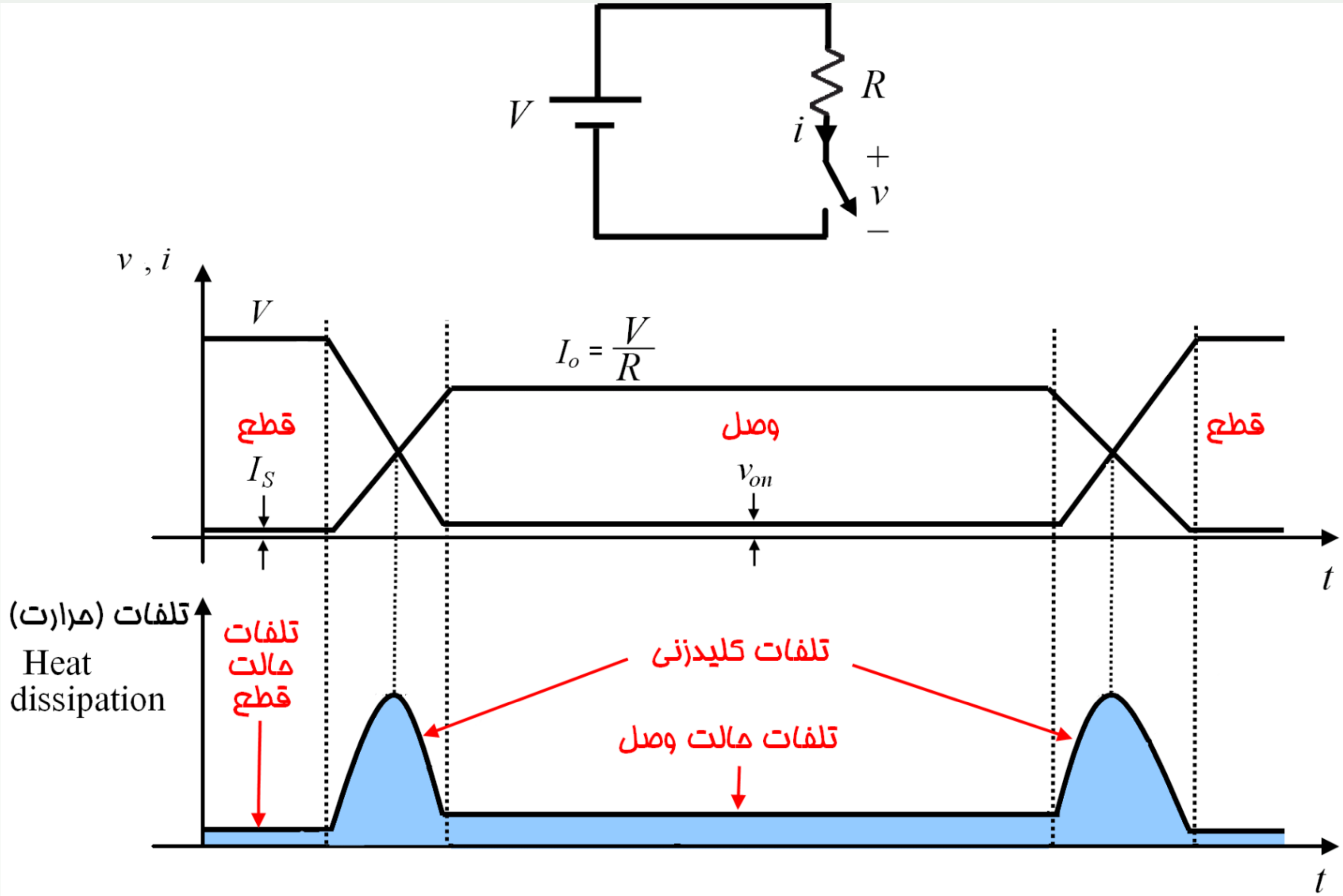
MOSFET	BJT
امپدانس ورودی بالا-کنترل شونده با ولتاژ	امپدانس ورودی کم-کنترل شونده با جریان
فرکانس کلیدزنی بالا	فرکانس کلیدزنی متوسط
افت ولتاژ هدایت مستقیم بیشتر	افت ولتاژ هدایت مستقیم کمتر
نویزپذیری بیشتر	نویزپذیری کمتر
کنترل راحت تر	کنترل مشکل تر
در قدرت های پایین تر موجود است	در قدرت های بالاتر موجود است
ضریب حرارتی مثبت	ضریب حرارتی منفی

Transistors (IGBT)

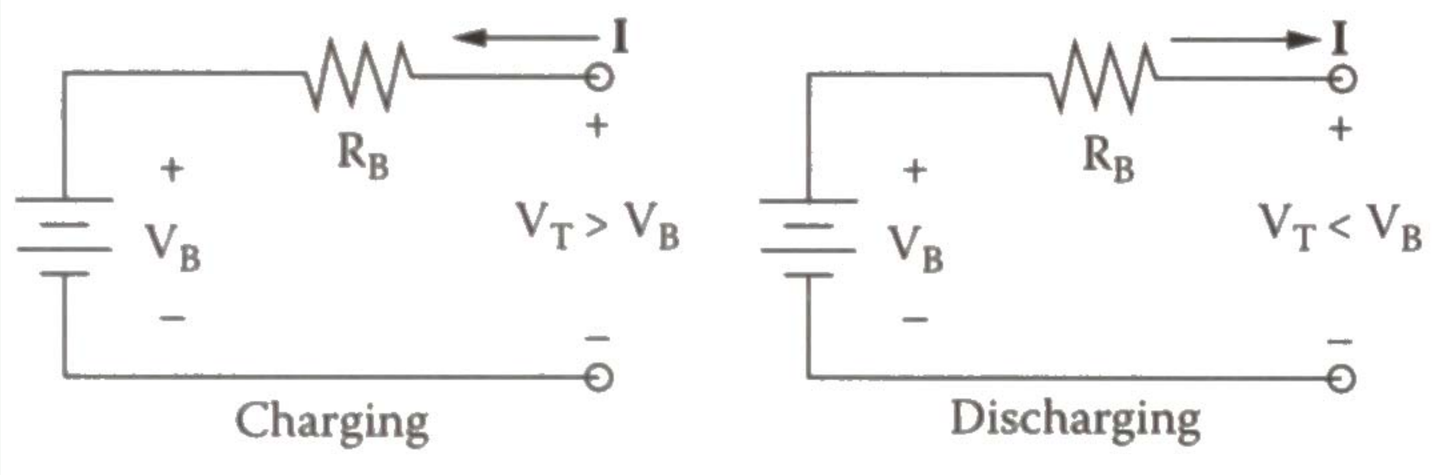
- در خروجي داراي مزاياي BJT يعني افت ولتاژ مستقيم كوچک (تلفات هدايت كم)
- در ورودي داراي مزاياي MOSFET يعني جريان ناچيز و سادگي مدار گيت
- ضريب حرارتي مثبت
  - سادگي موازي شدن
- سرعت كليدزني بين BJT و MOSFET
- جايگزين BJT در قدرت هاي متوسط و بالا



Losses in Transistors



Charge controllers



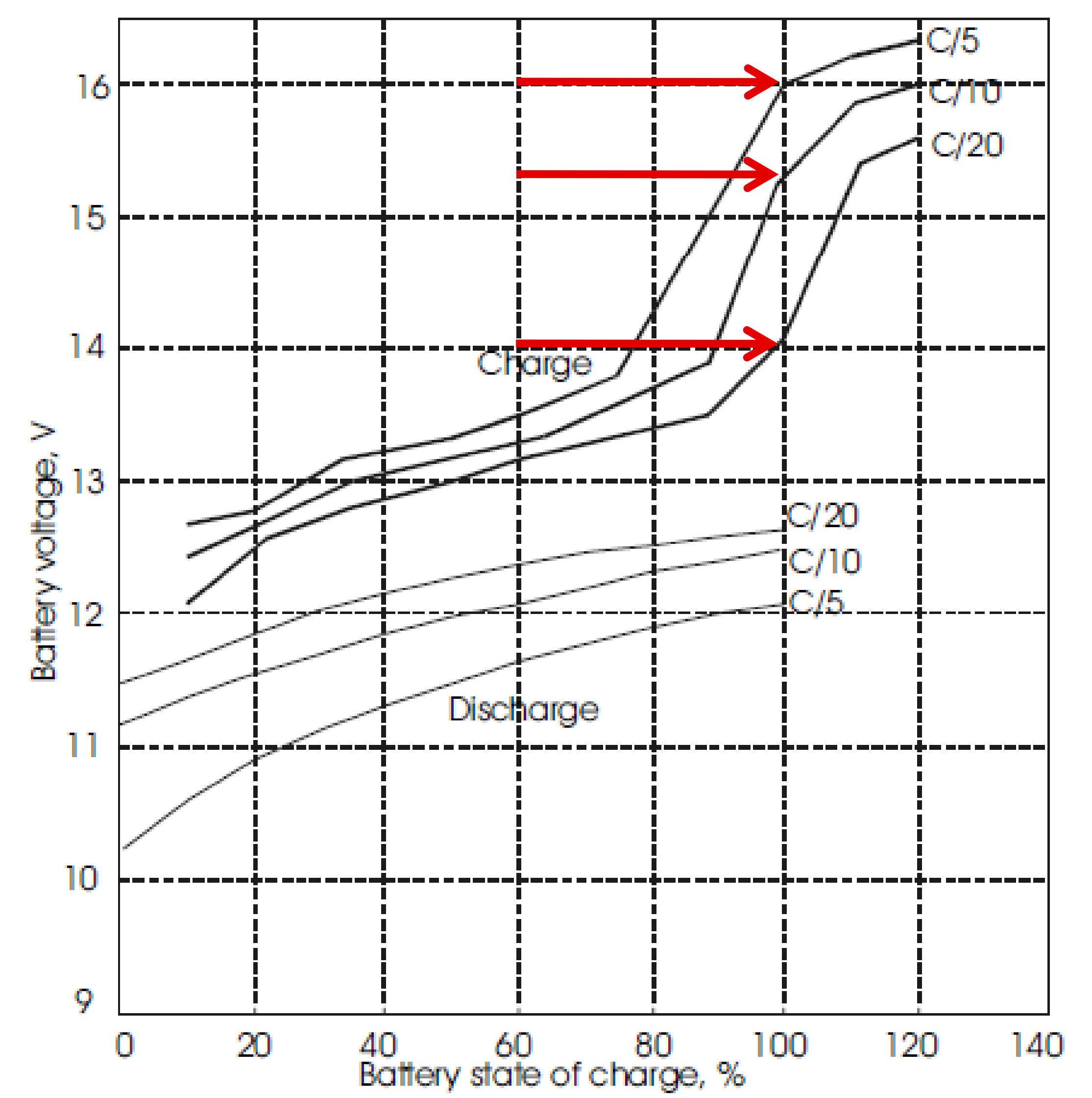
SOC (state of charge) can be measured by V_B

Is V_B available in charging condition?

Can one estimate V_B by knowing R_B?

Both V_B and R_B are temperature dependent.
R_B is age dependent too.

Charge Controllers



Let V=14 (C/20)

Disconnect

V decreases

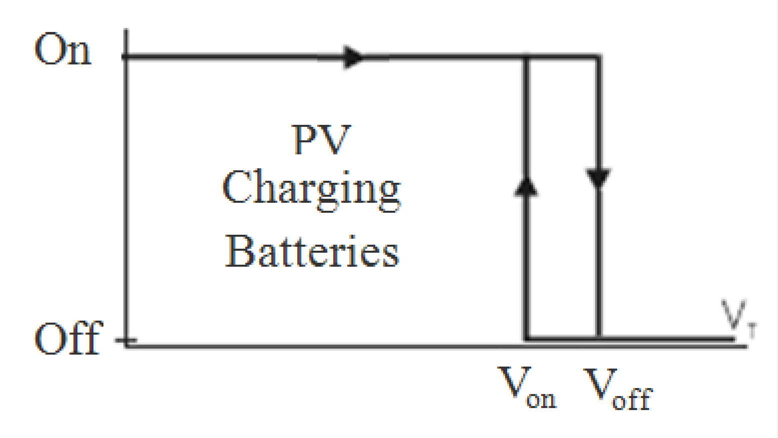
Connect

V increases

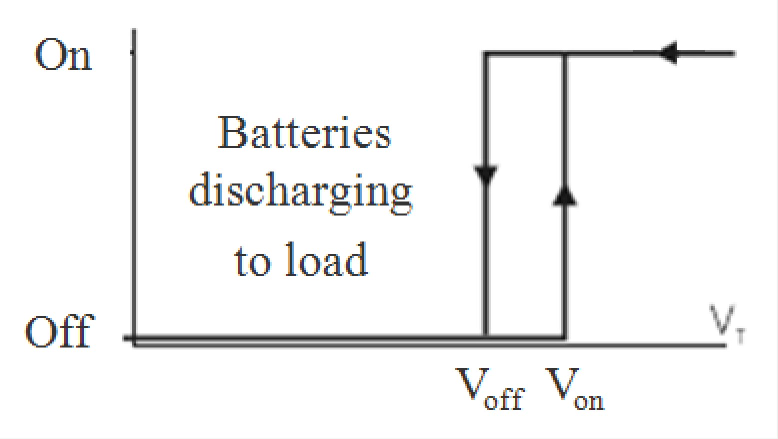
Charge Controllers

Hysteresis can help and solve the problem.

In the charging period:

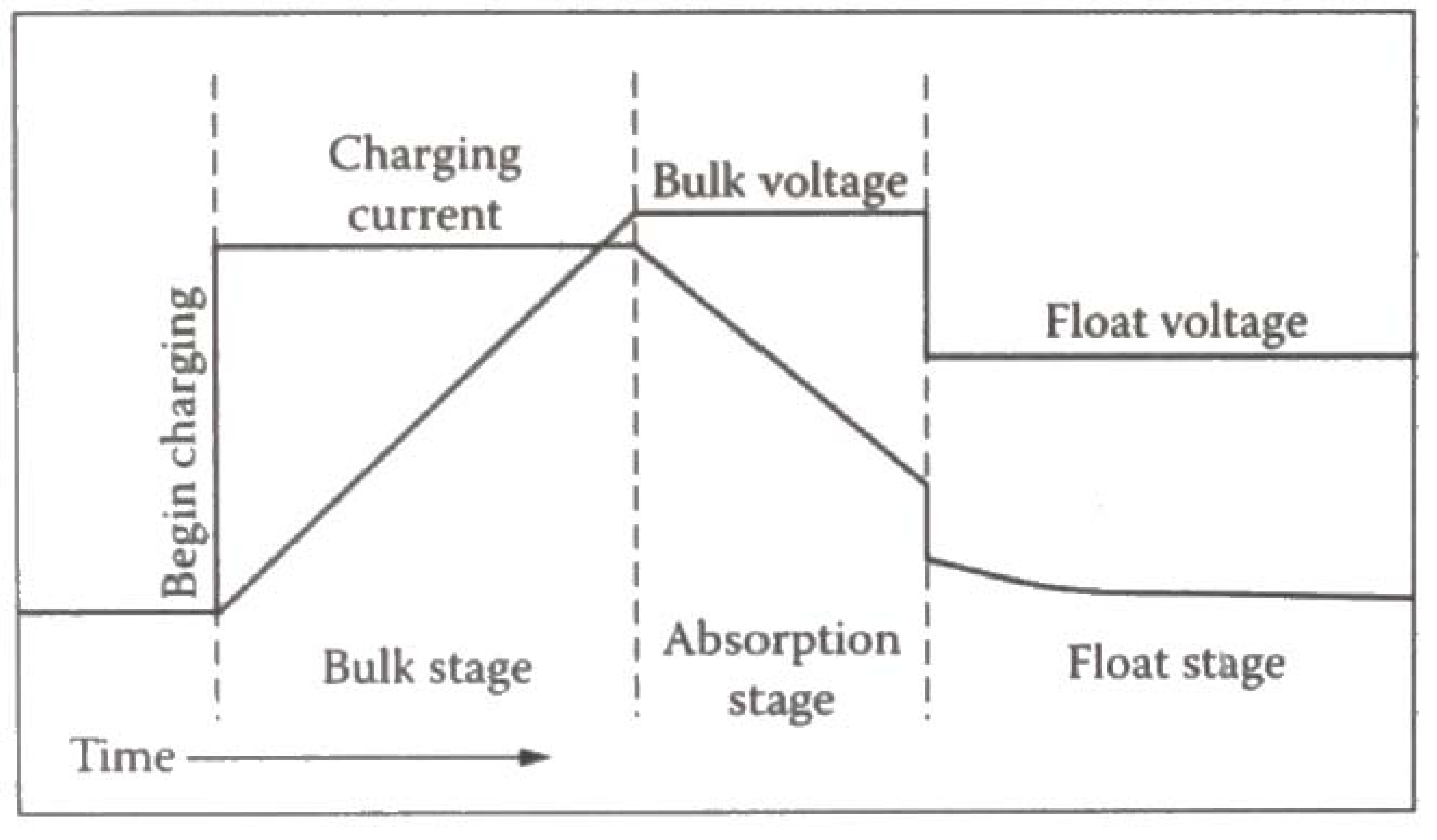


In the discharging period:

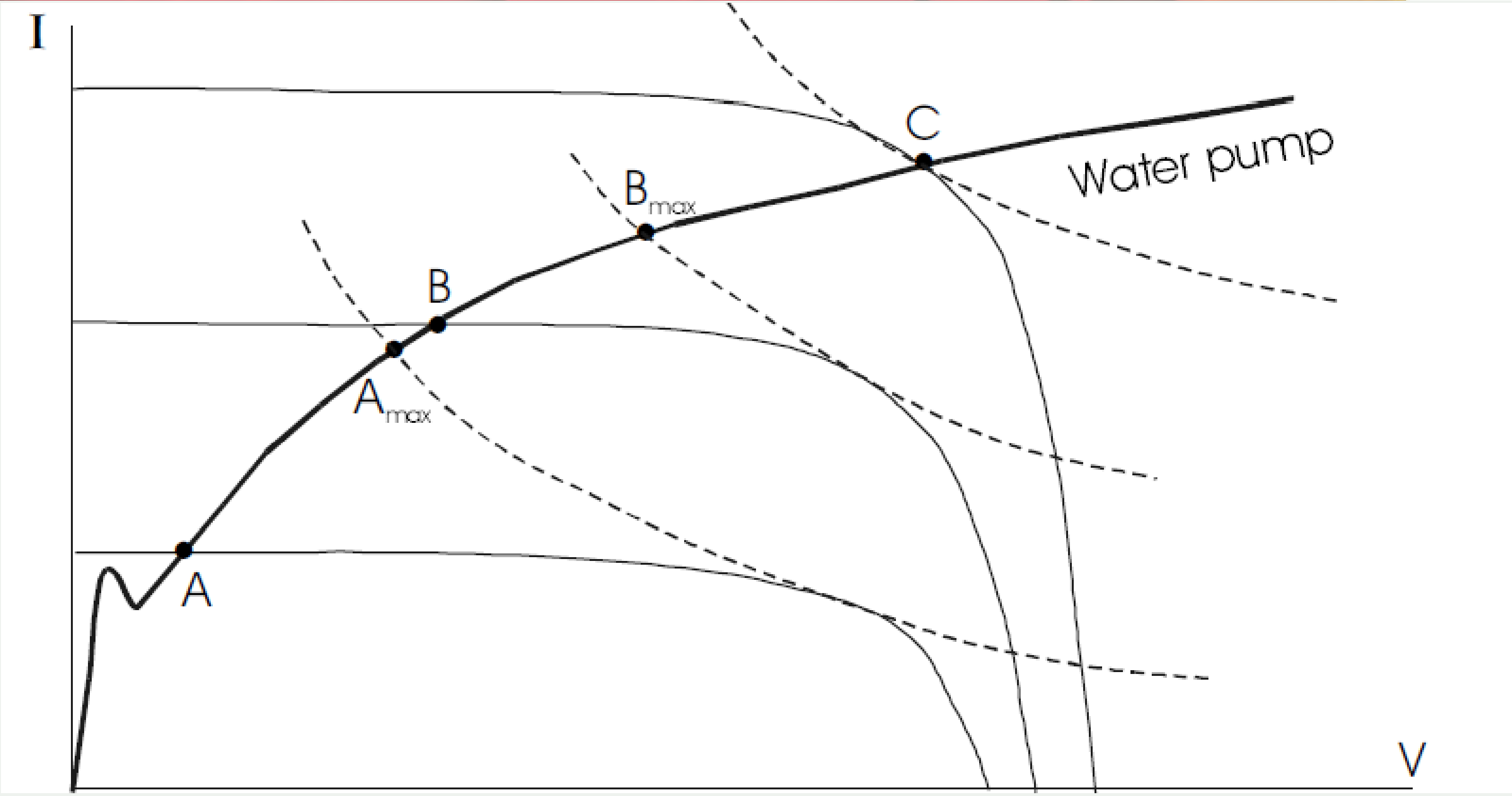


Charge Controllers

Three stage battery charge control



MPPT circuits



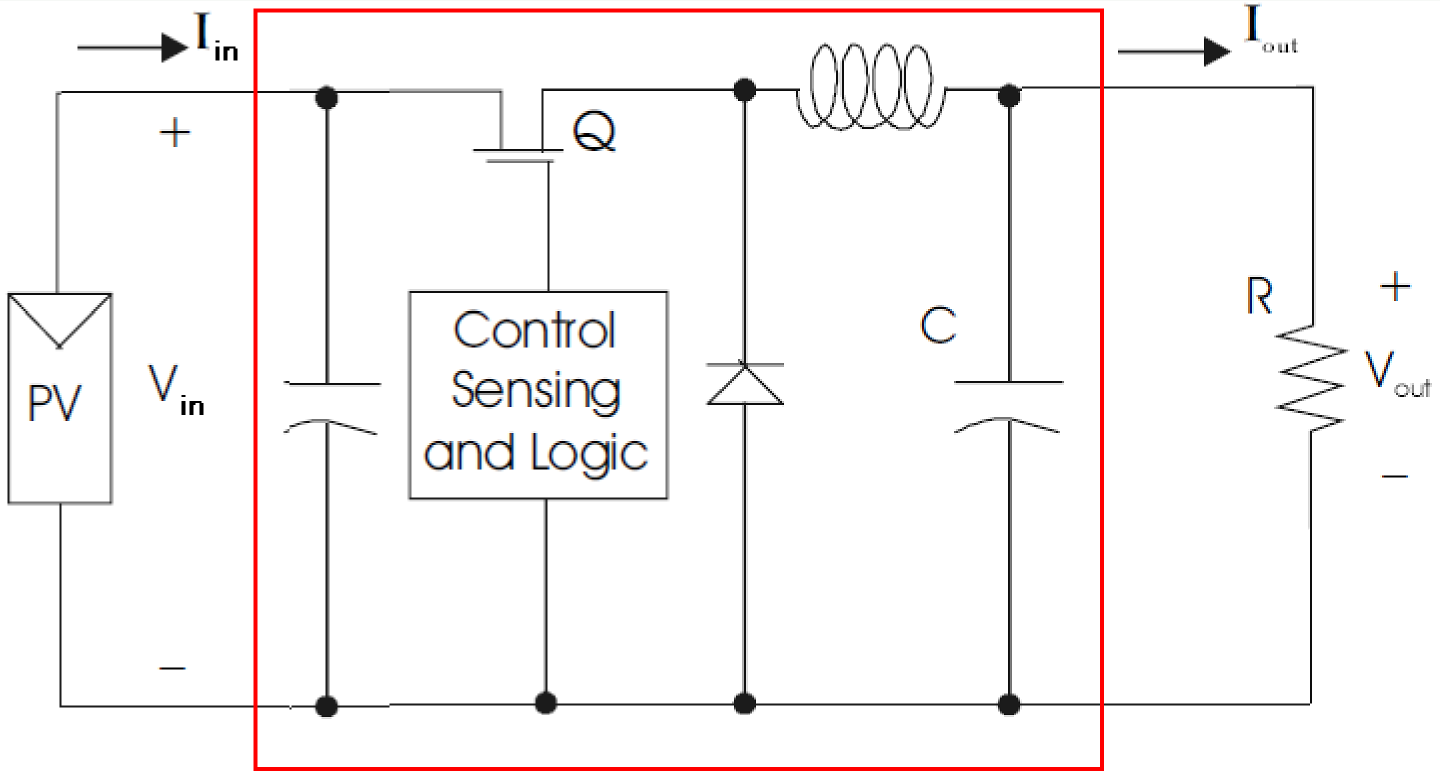
One must A→ A_{max} this is possible by an electronic circuit.

V_p must decrease and I_p must increase.

Use a buck convertor (Linear Current Booster)

MPPT circuits

A buck convertor (Linear Current Booster)

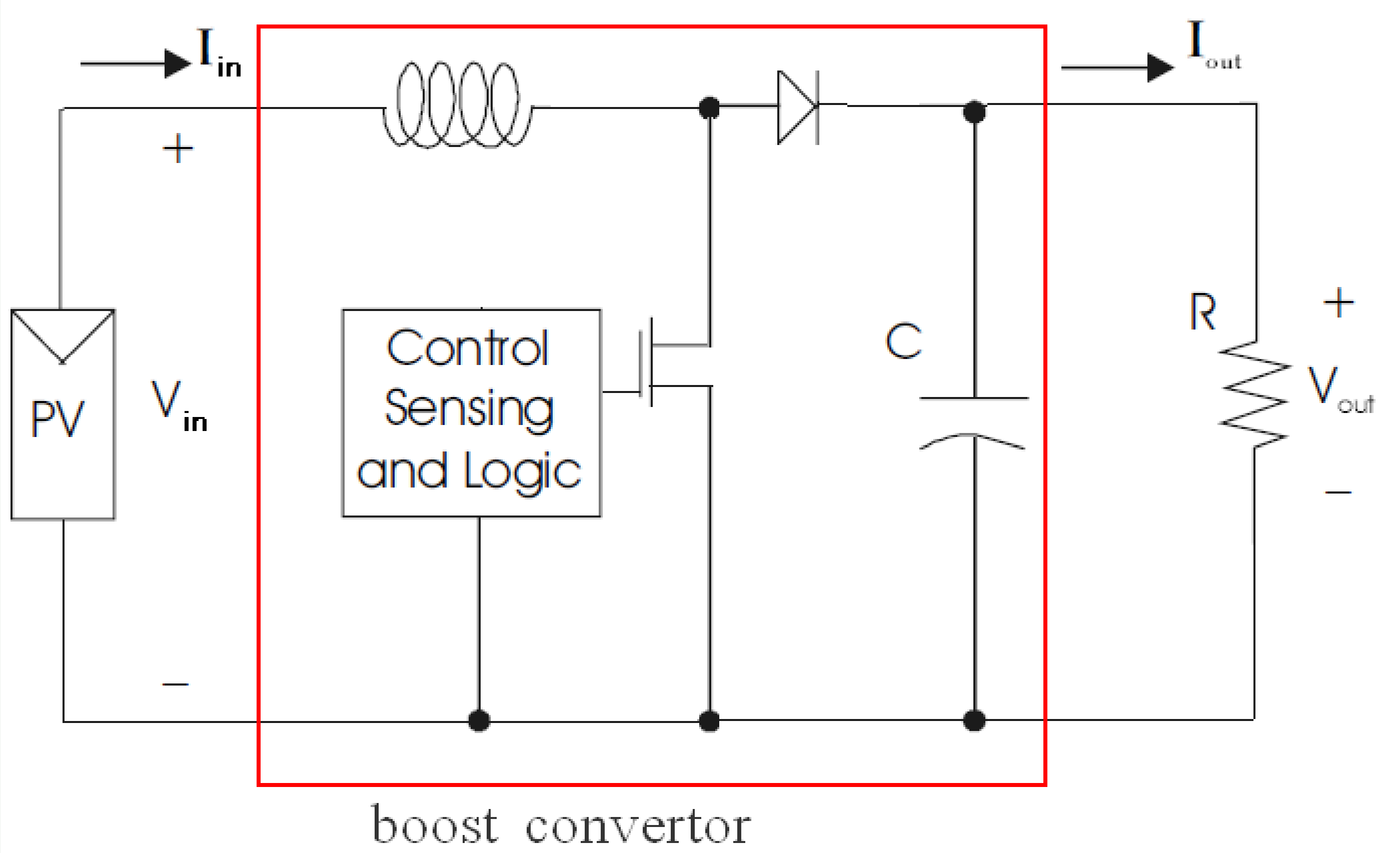


buck convertor

$$V_{out} = DV_{in} \ , \ I_{out} = I_{in} / D \ , \text{ where } D \text{ is duty cycle of MOSFET}$$

MPPT circuits

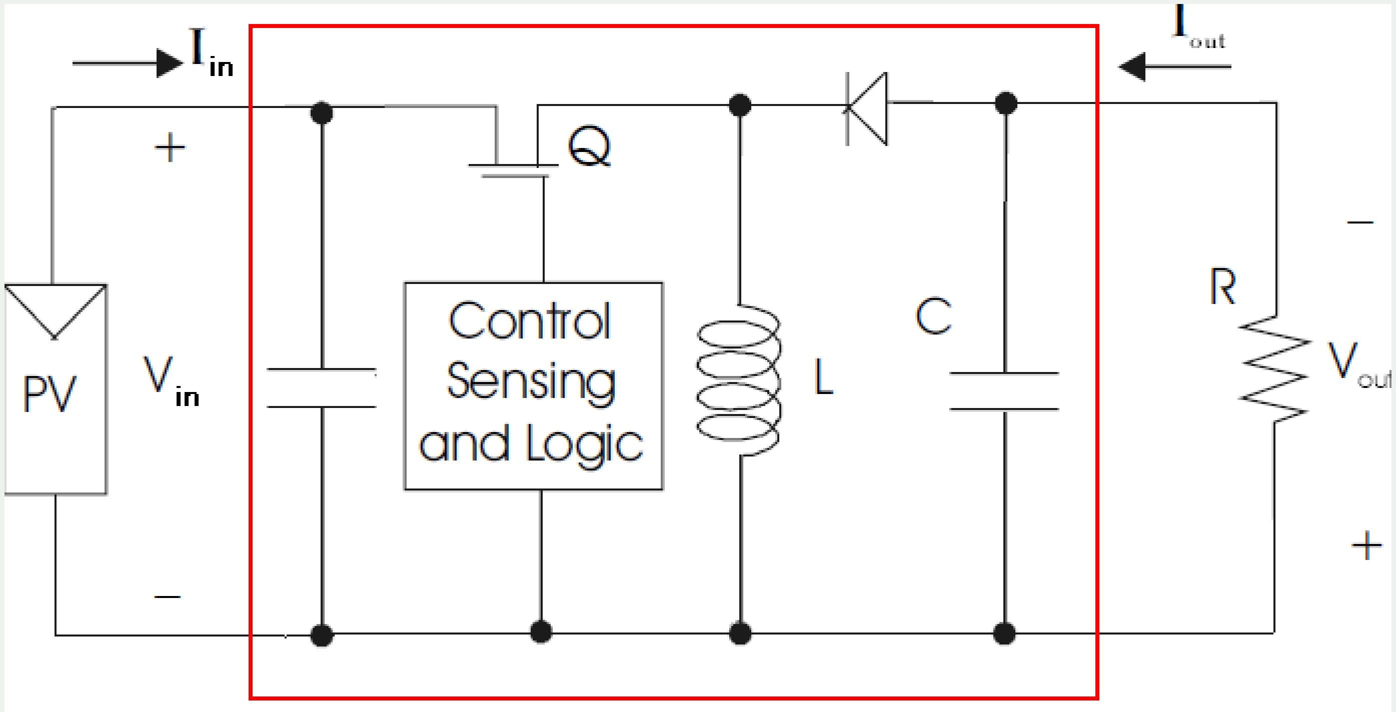
A boost convertor



$$V_{out} = \frac{1}{1-D} V_{in} \ , \ I_{out} = (1-D) I_{in} \text{ , where } D \text{ is duty cycle of MOSFET}$$

MPPT circuits

A buck-boost convertor



buck-boost convertor

$$V_{out} = \frac{D}{1-D} V_{in} \ , \ I_{out} = \frac{(1-D)}{D} I_{in} \text{, where } D \text{ is duty cycle of MOSFET}$$

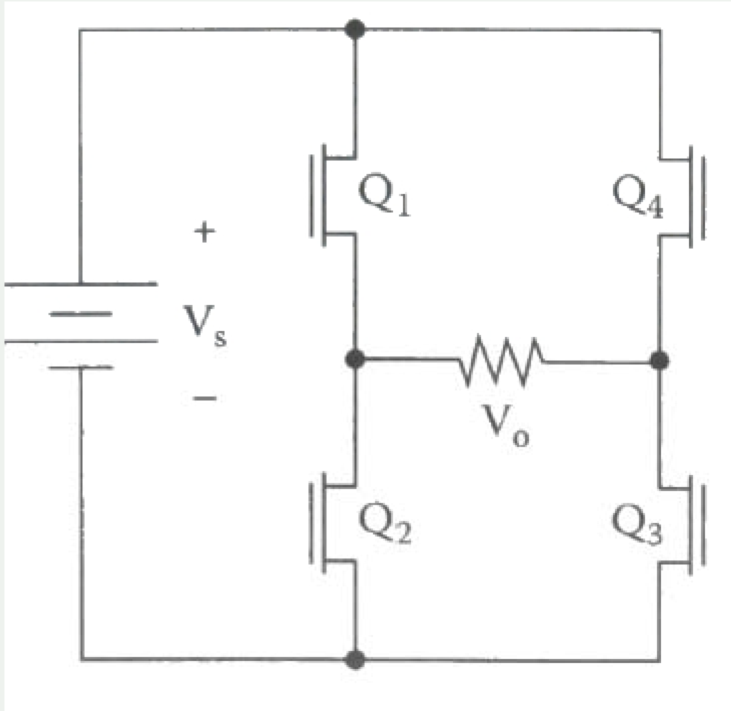
Inverters

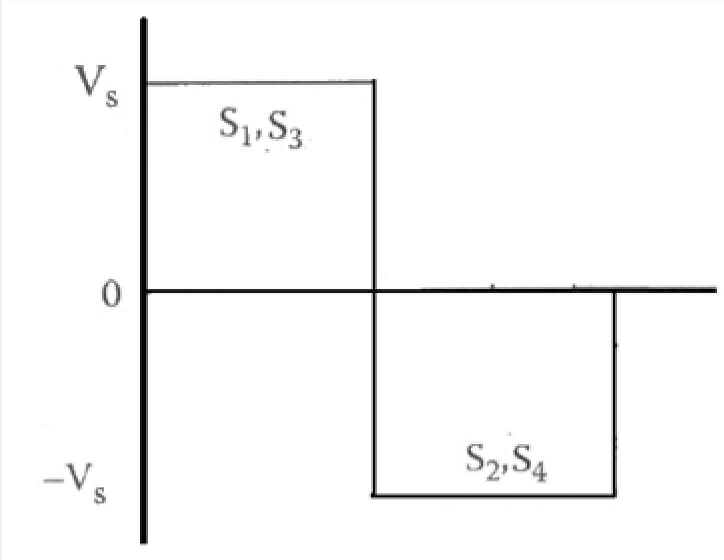
Different type Of Inverters:

- Square Wave Inverters
- Modified Sine Wave Inverters
- Pulse Width Modulated Inverters

Square Wave Inverters

Conventional Inverter (Square wave inverters)

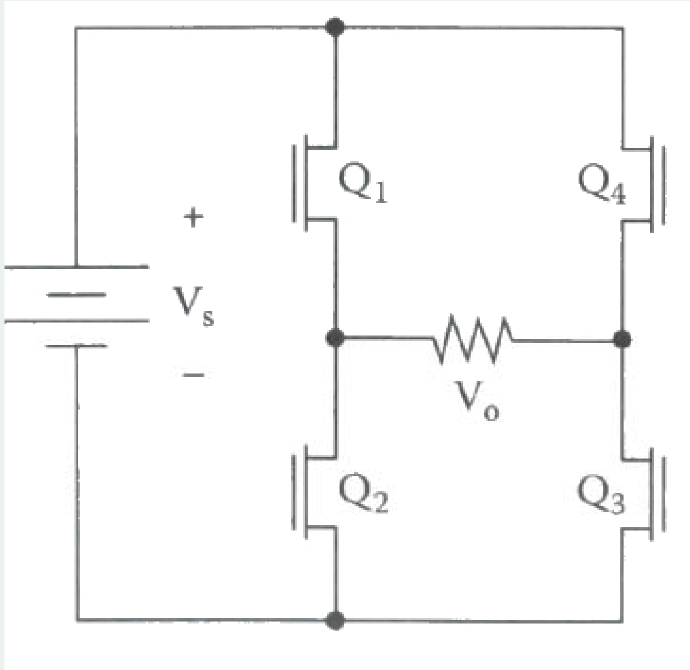


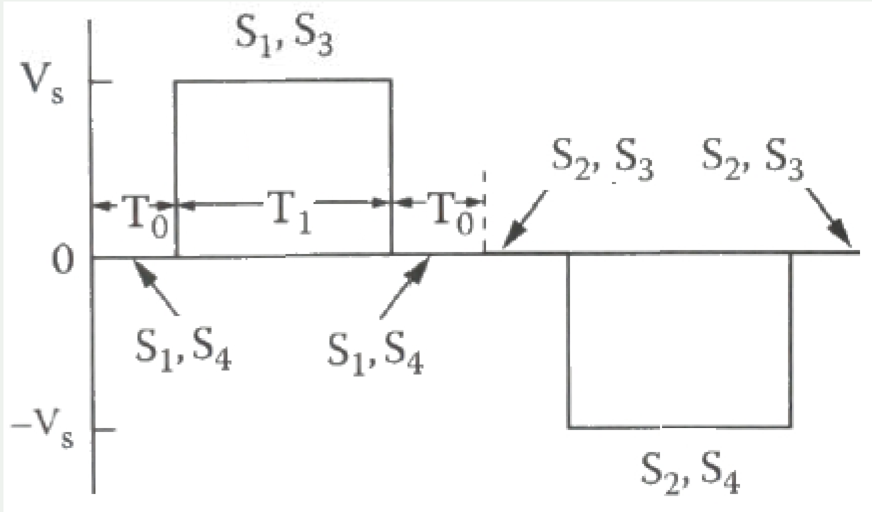


Harmonics?

Modified Square Wave Inverters

Modified square wave inverters

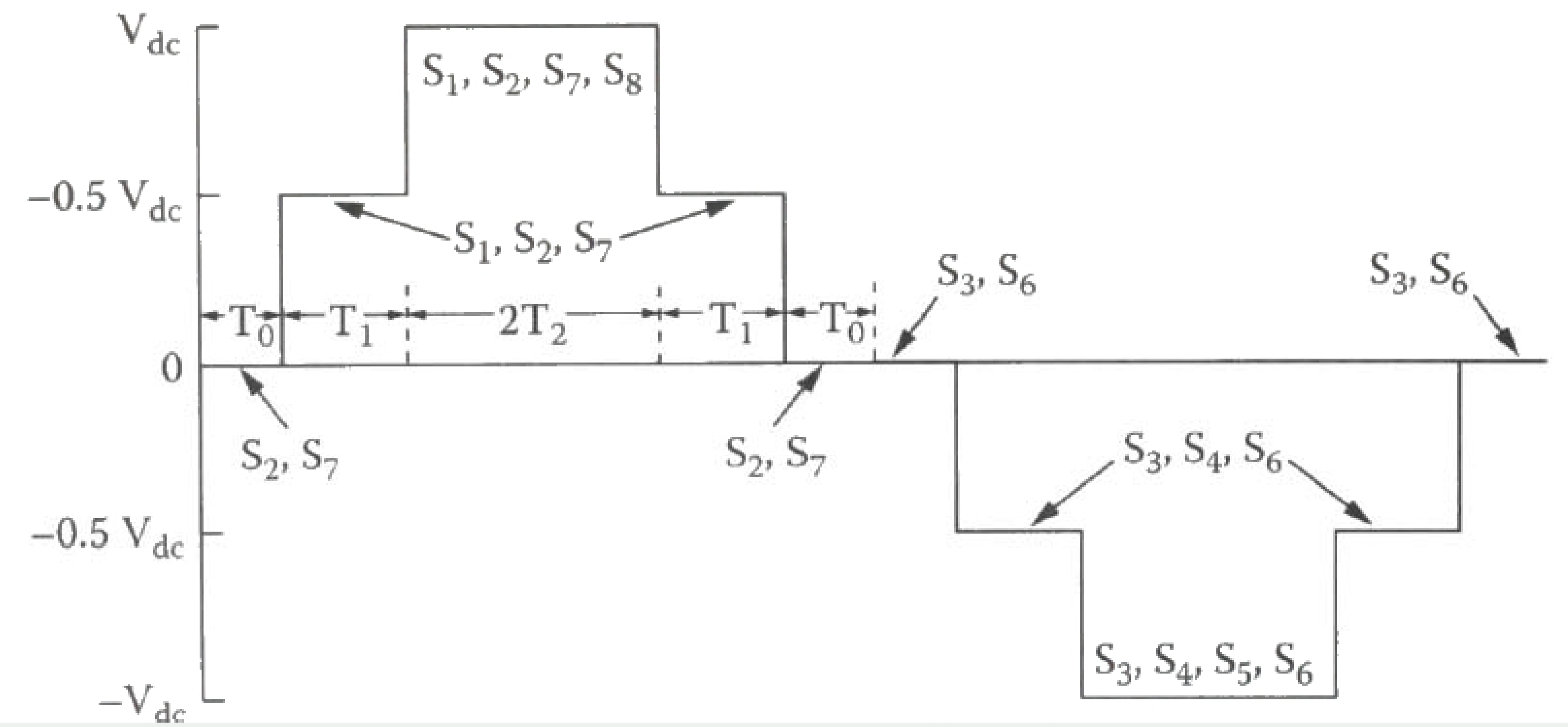




Harmonics?

Modified Square Wave Inverters

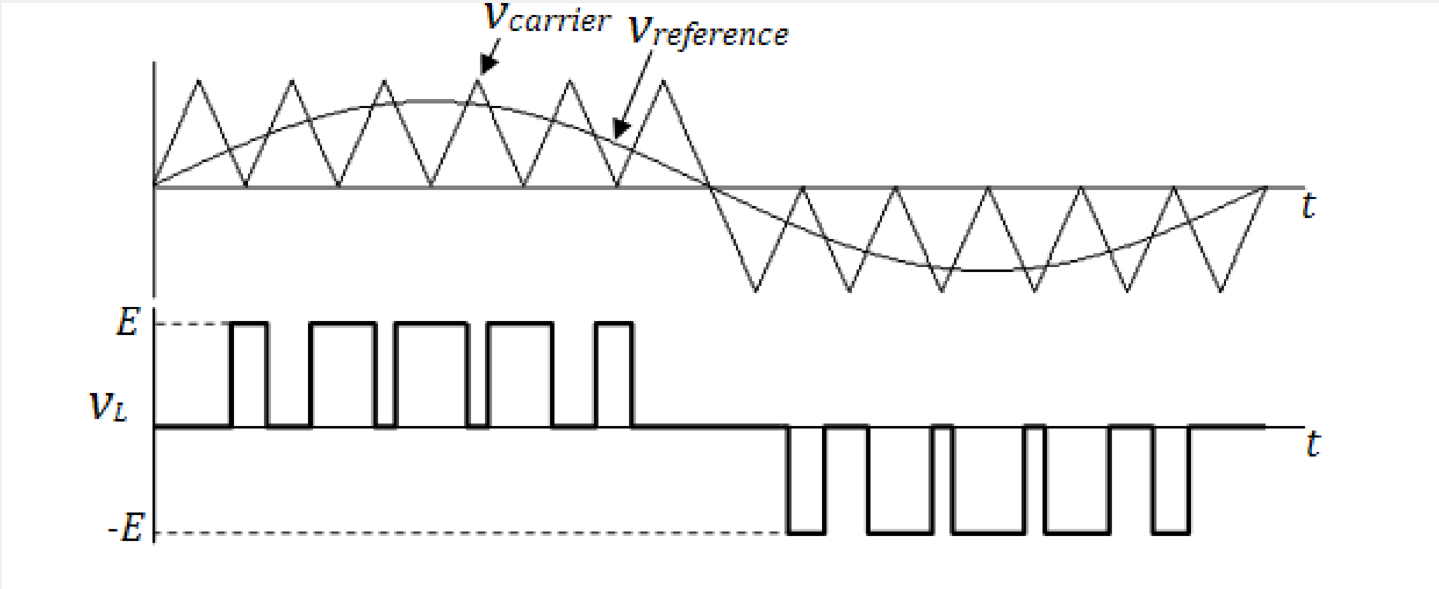
Multi Level Converters



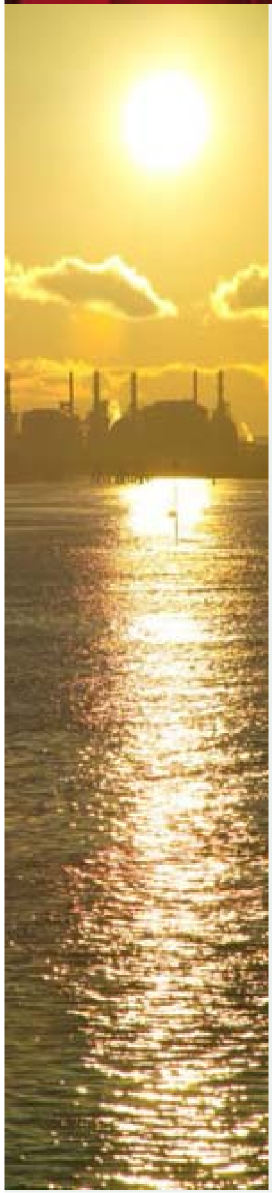
Harmonics?

PWM Inverters

Unipolar SPWM, $m_a = 0.8$:

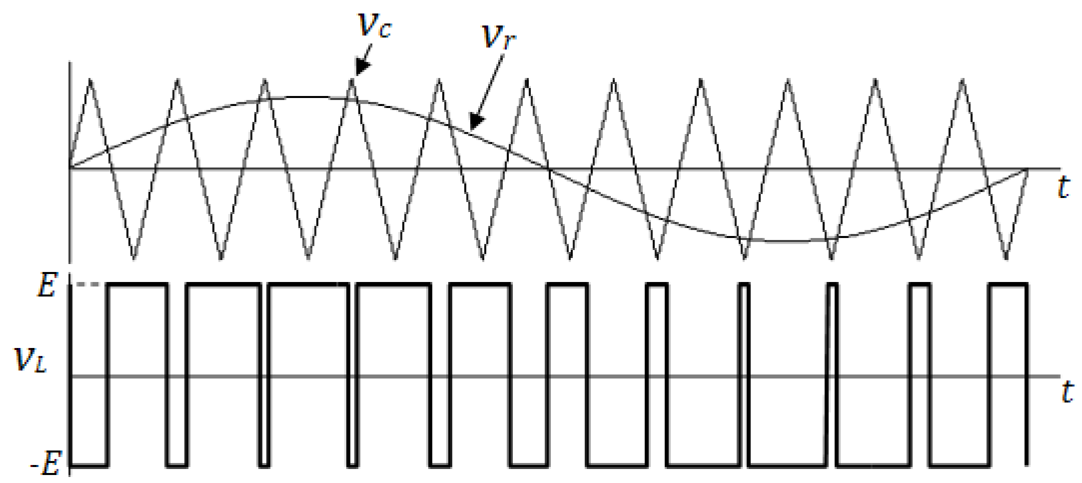


PWM Inverters

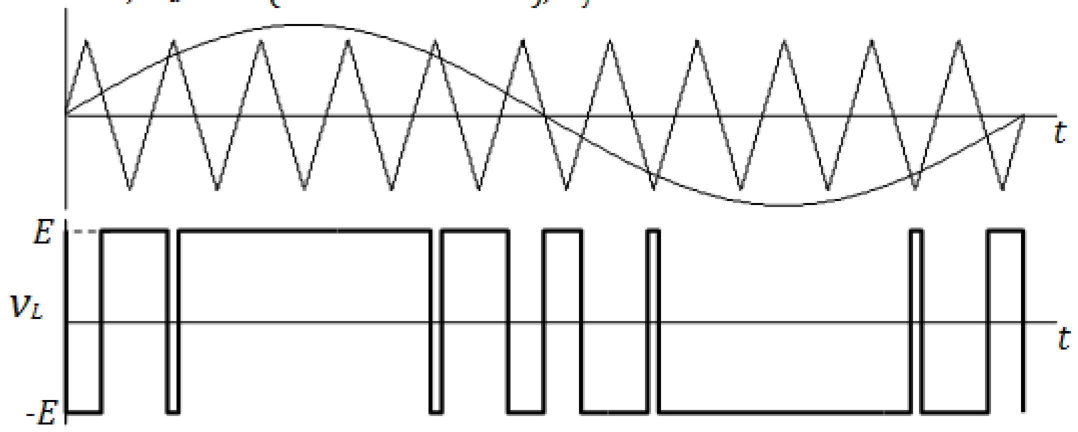


Basis of PWM is shifting harmonic frequency and filtering them.

Bipolar SPWM, $m_a = 0.8$(linear), $m_f = 11$:



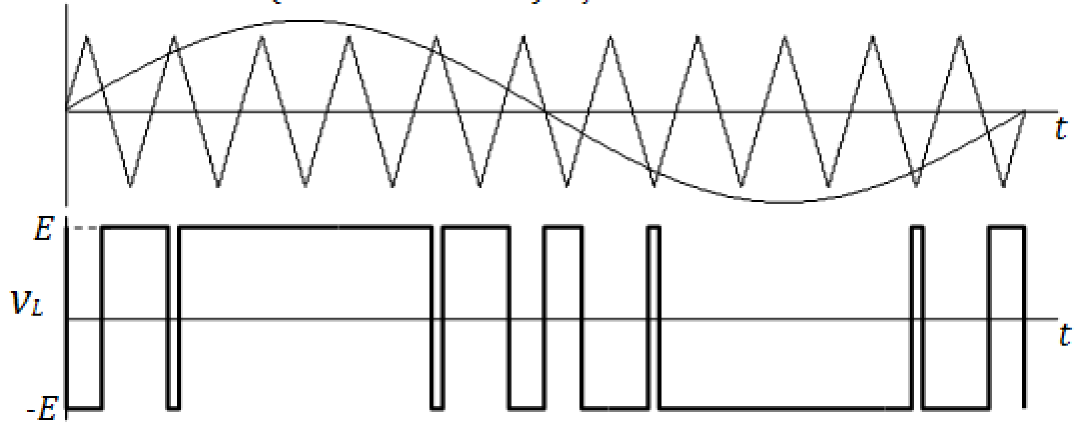
Bipolar SPWM, $m_a = 1.2$ (overmodulation), $m_f = 11$:



PWM Inverters

Basis of PWM is shifting harmonic frequency and filtering them.

Bipolar SPWM, $m_a = 1.2$ (overmodulation), $m_f = 11$:



PWM Inverters