Maximum Power Point Tracking in Solar PV Systems

CEP Course on "Converter Topologies for Grid Connected PV System"

Prof. Suryanarayana Doolla
Dept. of Energy Science and Engineering
Indian Institute of Technology Bombay

NCPRE

Outline

- Need of MPPT and its History
- Various Techniques
  - Analysis
- Summary

Need of MPPT

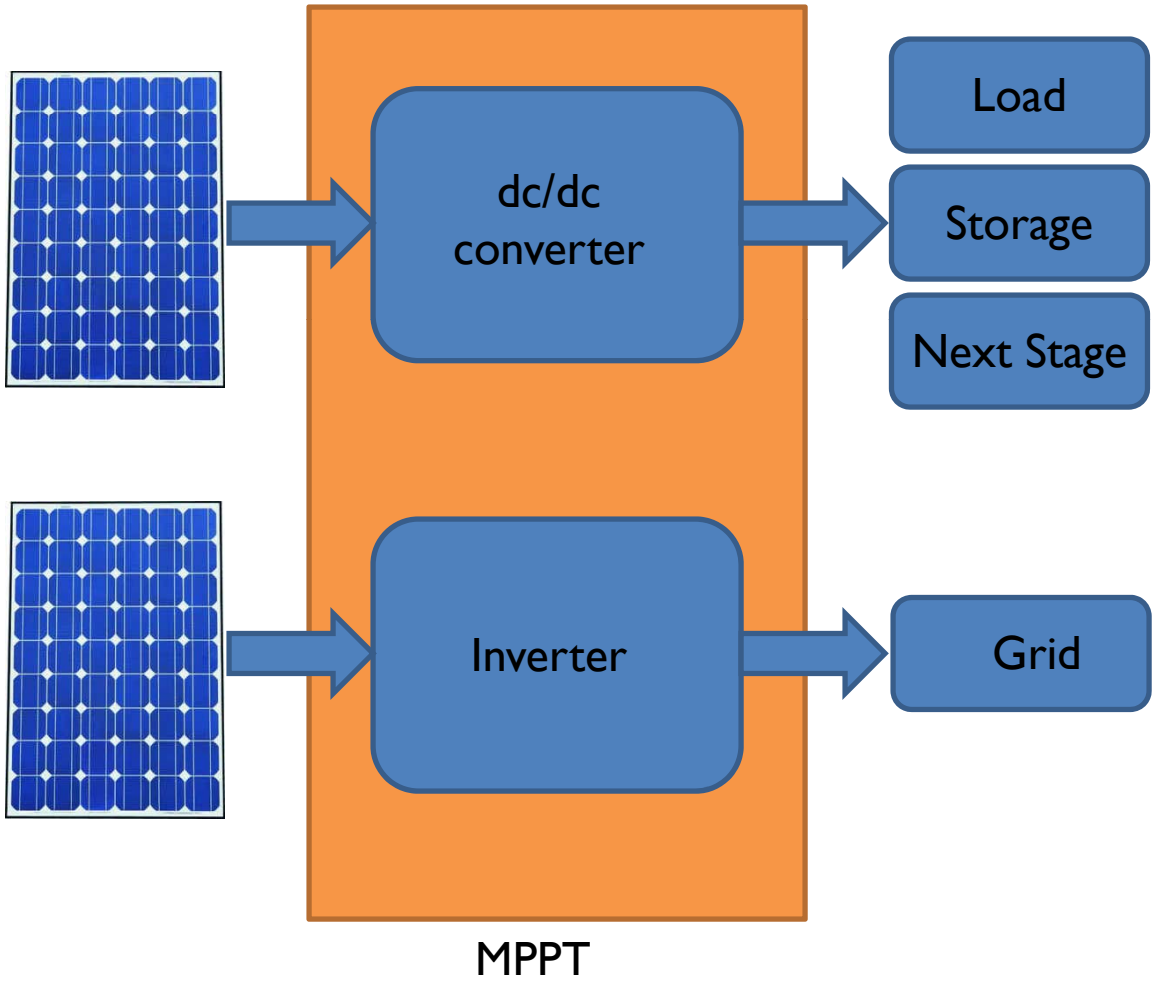
- PV power is increasingly connected to grid
  - Large Scale
  - Small Scale
- Efficiency of Solar PV Cells
- Earliest MPPT methods published in 1960s
- Several methods are proposed in literature
  - Direct method
  - Indirect method
    - Short Circuitt, Open Circuit
      - Prior evaluation of panel, based on mathematical relationships, Database not valid for all operating and meteorological conditions

Maximum Power Point Tracking

- To automatically find the voltage (V_{MPP}) or current (I_{MPP}) at which a PV array should operate to obtain the maximum power output (P_{MPP})under a given temperature and irradiance.

- Partial shading conditions
  - It is possible to have multiple local maxima, but overall there is still only one true MPP.

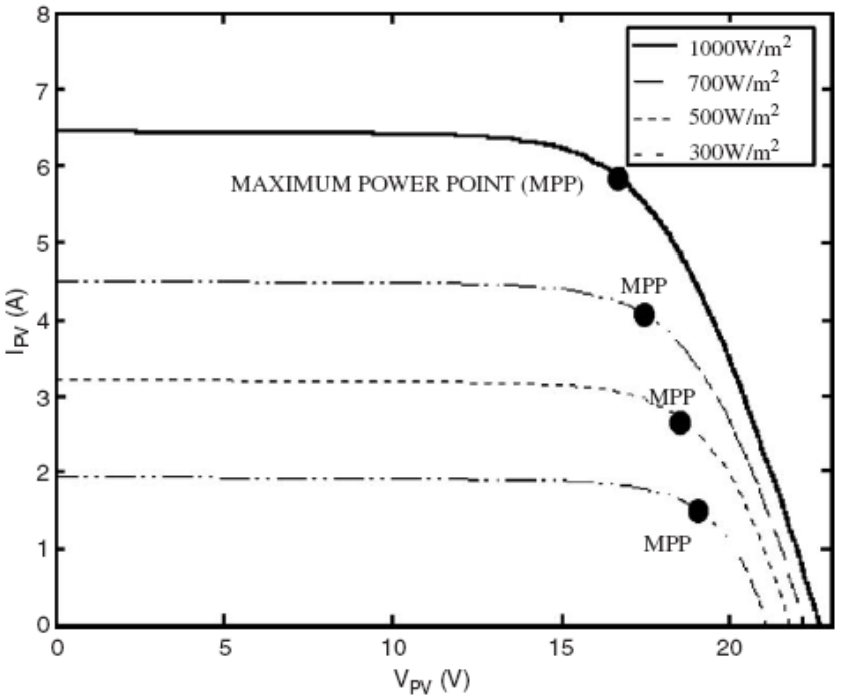
Topology



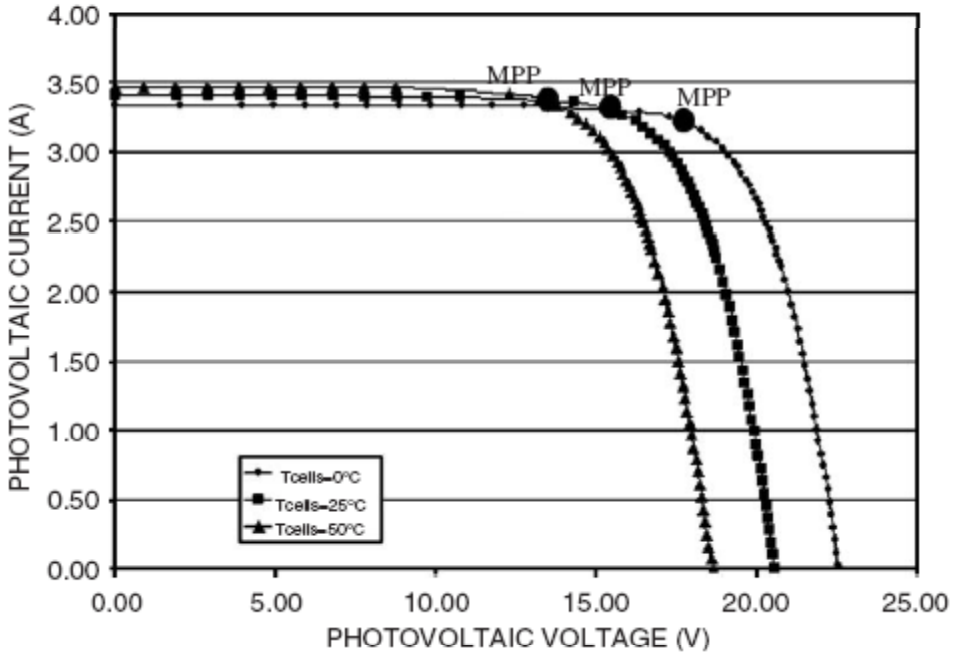
Choice of MPPT Technique

- Implementation complexity
- Sensors required
- Ability to detect multiple local maxima
- Cost
- Application
- Response time

I-V Curve

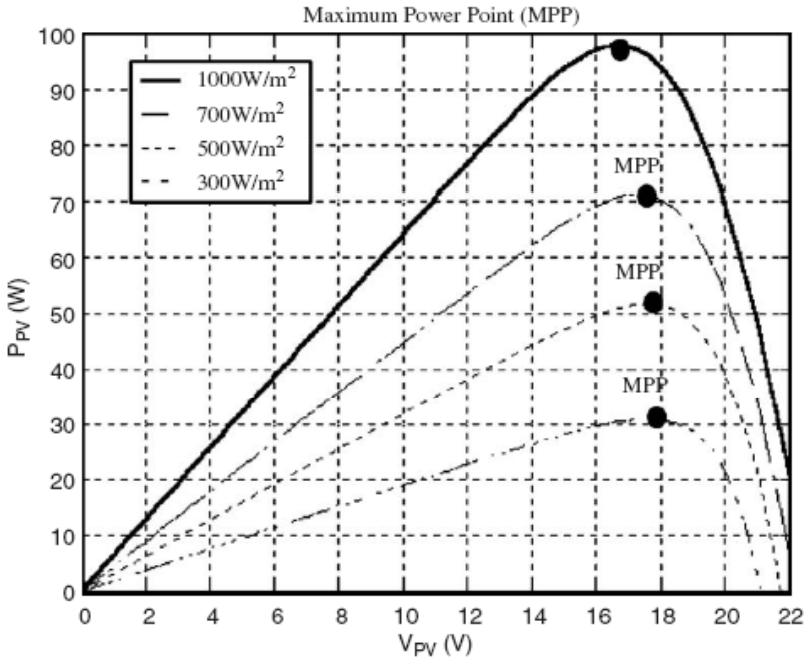


I-V Characteristics at four different radiation levels

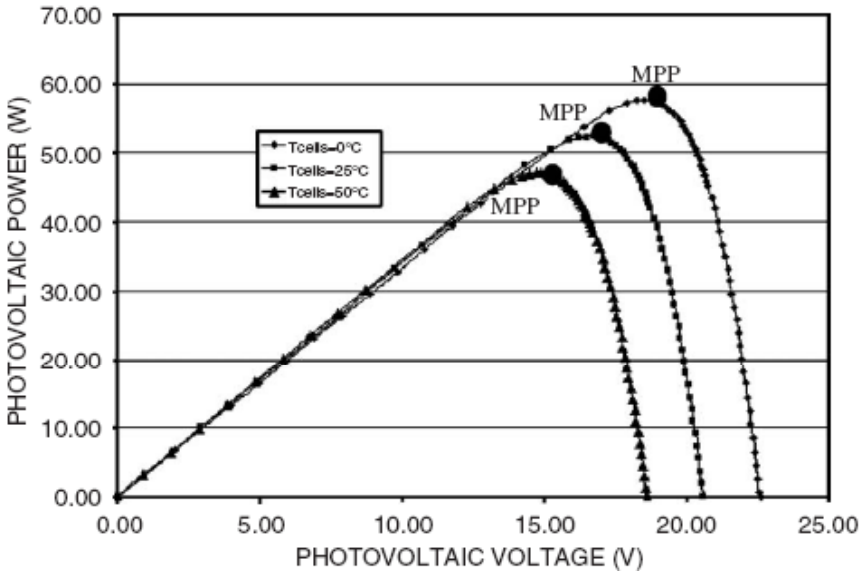


I-V Characteristics for three different temperature levels

P-V Curve



P-V Characteristics at four different radiation levels



P-V Characteristics for three different temperature levels

Indirect Methods (quasi seeks)

- MPP is estimated from
  - Voltage
  - Current
  - The irradiance
  - Using empirical data
  - Mathematical expressions of numerical approx.
- The estimation is carried out for a specific PV generator installed in the system
- Some Techniques
  - Curve fitting method
  - Lookup table method
  - Fractional OC method
  - Fractional SC method

Direct Methods (true seeking)

- Use voltage and/or current information
- Prior knowledge of PV panel is not required
- Independent of isolation, temperature and degradation levels
- Computational intensive
- Some Techniques
  - Hill climbing/P&O
  - Incremental Conductance
  - Fuzzy Logic Control
  - Slide Control Method

Fractional Open-Circuit Voltage

- Near linear relationship between V_{OC} and V_{MPP}

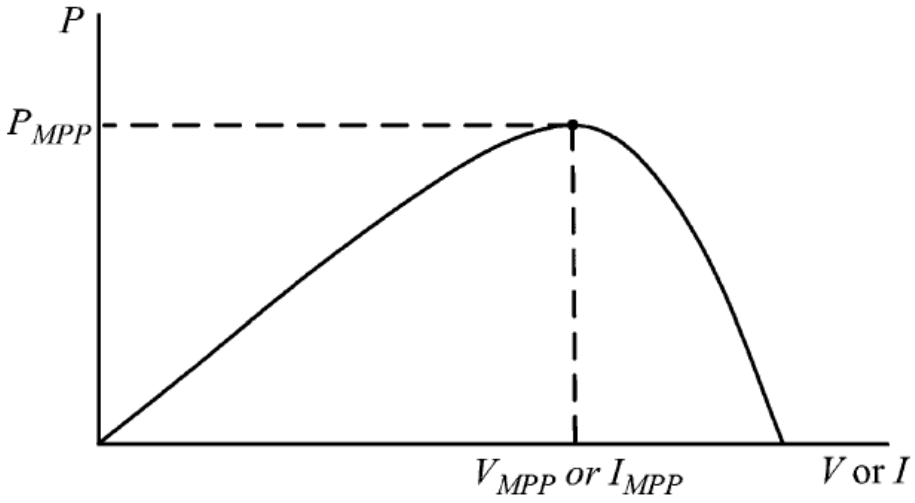
$$V_{MPP} \approx k_1 V_{OC}$$

- k_1 is a constant of proportionality (0.71-0.78)and depends on
  - characteristics of the PV array being used
  - computed beforehand emperically
    - V_{MPP} and V_{OC} for specific PV array at different irradiance and temperature
- Once k_1 is known, V_{OC} is measured by shutting down the converter, periodically.
  - Power loss associated with shutting down
- Pilot cells can be used parallelly
- PV array never operates at MPP (approximation)
- Not valid in case of partial shading

Source: H.-J. Noh, D.-Y. Lee, and D.-S. Hyun, "An improved MPPT converter with current compensation method for small scaled PV-applications," in Proc. 28th Annu. Conf. Ind. Electron. Soc., 2002, pp. 1113–1118

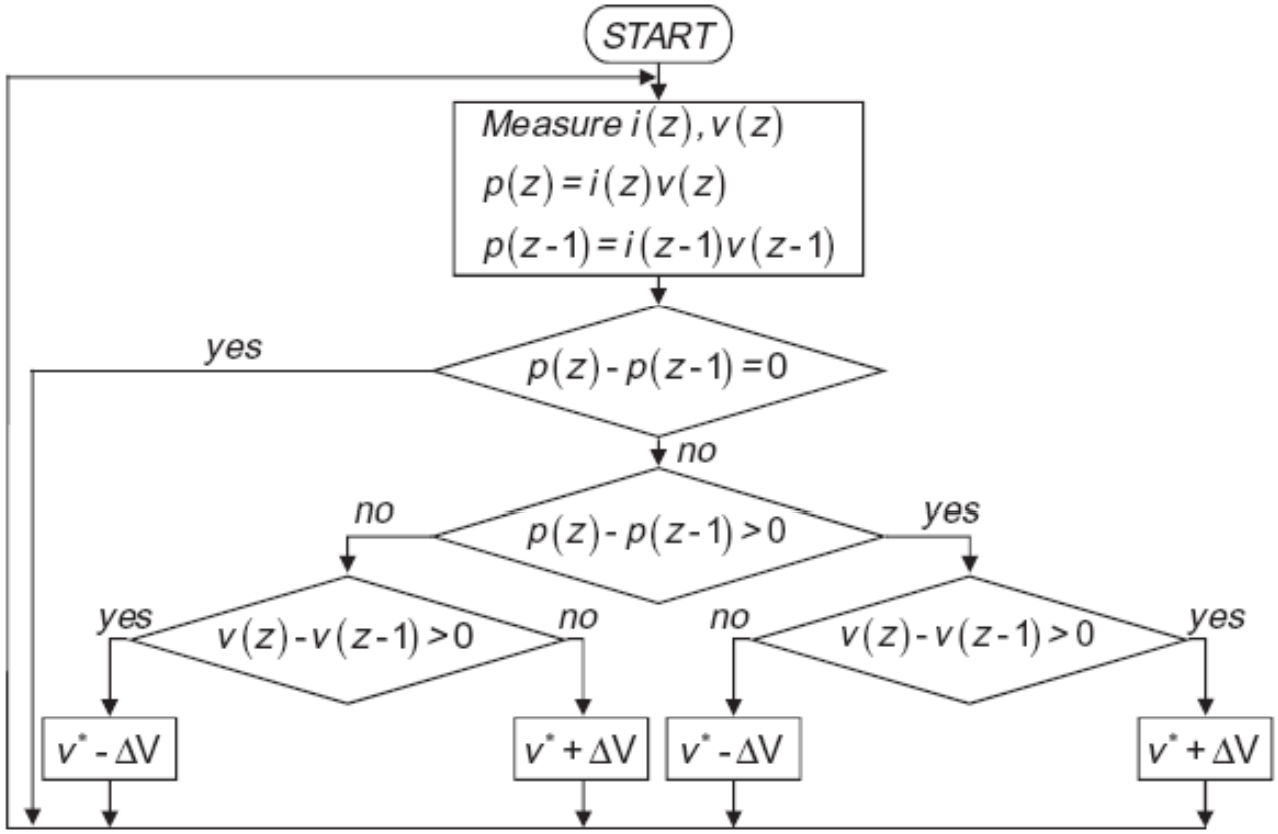
Hill Climbing/Perturb & Observe Technique

- Incrementing the voltage increases the power when operating on the left of the MPP and decreases the power when on the right of the MPP.
- Hill climbing involves a perturbation in the duty ratio
- P&O a perturbation in the operating voltage of the PV array



Perturbation	Change in Power	Next Perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

Flow Chart for P&O Algorithm

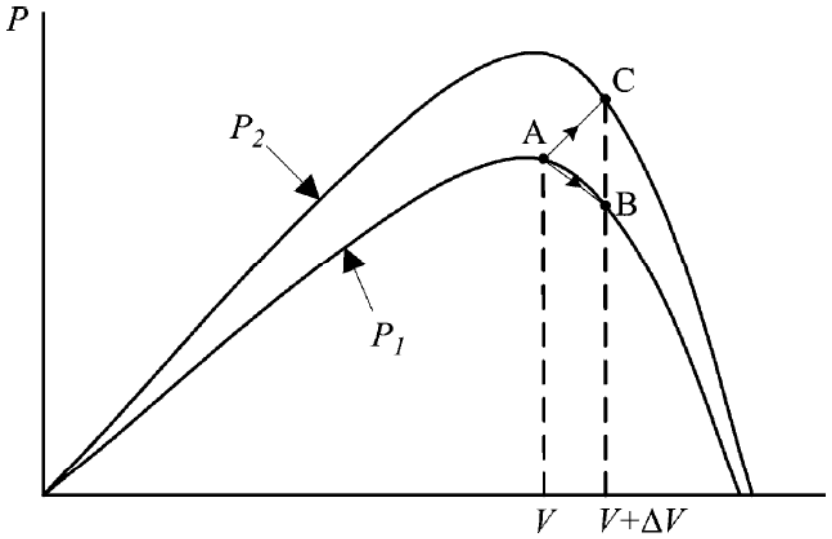


Source: *I. Houssamo et al. / Electrical Power and Energy Systems 46 (2013) 98–107*

Hill Climbing/Perturb & Observe Technique

- Hill climbing and P&O methods can fail under rapidly changing atmospheric conditions
- If the irradiance increases and shifts the power curve from P_1 *to* P_2 *within one* sampling period, the operating point will move from A to C.
- A three-point weight comparison P&O
  - Compares the actual power point to two preceding ones before a decision is made about the perturbation sign

- Can be implemented using digital/analog circuitry
- Two sensors are required to implement



Hill Climbing/Perturb & Observe Technique

- The process is repeated periodically until the MPP is reached.
- The system then oscillates about the MPP.
  - The oscillation can be minimized by reducing the perturbation step size.
  - Smaller perturbation size slows down the MPPT.
  - Variable perturbation size that gets smaller towards the MPP
    - Fuzzy logic control is used to optimize the magnitude of the next perturbation.

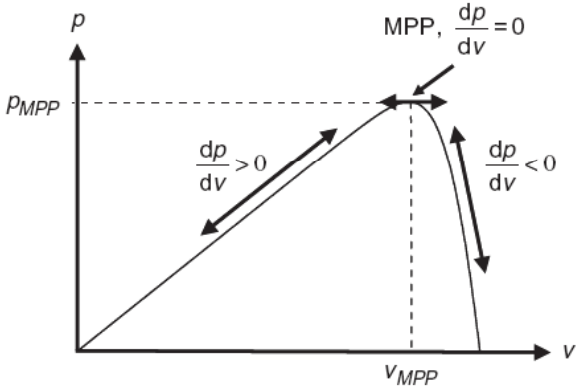
Incremental Conductance

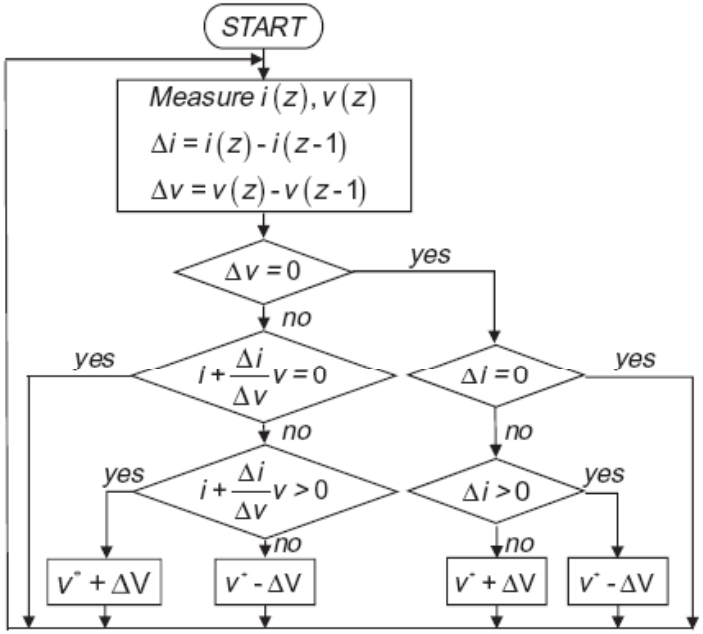
- Based on fact that the slope of p-v
  - Zero at MPP
  - Negative on right of MPP
  - Positive on left of MPP
- The MPP can e tracked by comparing the instantaneous conductance (I/V) to the incremental conductance

$$\frac{dp}{dv} = \frac{d(vi)}{dv} = i + v\frac{di}{dv} \qquad \frac{i}{v} + \frac{di}{dv} = 0$$

$$di \approx \Delta i = i(z) - i(z-1)$$
$$dv \approx \Delta v = v(z) - v(z-1)$$

- The algorithm can instantly calculate i/v and di/dv to deduct the direction of the perturbation leading to the MPP





K. H. Hussein and I. Mota, "Maximum photovoltaic power tracking: An algorithm for rapidly changing atmospheric conditions," in IEE Proc. Generation Transmiss. Distrib., 1995, pp. 59–64.

Comparison- P&O and INC Methods

- Concerning power efficiency, theoretically, INC method could provide a better tracking of MPP than P&O algorithm
- Due to the noise and error measurements it is difficult to satisfy some of the equations
- It produces oscillations around the MPP and power loss
- Complex to implement when compared to P&O
- Tracking step value has a significant effect on effectiveness of MPPT
- When tracking step value is chosen correctly, P&O can have an energy efficiency equivalent to that obtained with INC
- Modified to obtain MPP even in partial shading conditions

Major Characteristics - Comparison

Technique	Array dependent	True MPPT?	Analog or Digital	Periodic Tuning	Convergence Speed	Implementation Complexity	Sensed parameters
P&O	NO	YES	Both	NO	Varies	Low	V, I
INC	NO	YES	Digital	NO	Varies	Medium	V, I
Frac V_{OC}	YES	NO	Both	Yes	Medium	Low	V
Frac I_{SC}	YES	NO	Both	Yes	Medium	Medium	I
RCC	NO	YES	Analog	NO	Fast	Low	V, I
dp/dv or dp/di	NO	YES	Digital	NO	Fast	Medium	V, I
I_{mpp} and V_{mpp}	YES	YES	Digital	Yes	N/A	Medium	Irradiance, temperature
OCC	Yes	No	Both	Yes	Fast	Medium	Current
Current Sweep	Yes	Yes	Digital	Yes	Slow	High	V, I

Source: T. Esram, and P. L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques," IEEE transactions on energy conversion, vol. 22, no. 2, june 2007.

Applications

- Space and Orbital Stations
  - Cost and complexity are not an issue,
  - High Reliability and performance
  - Hill climbing/P&O, IncCond, and RCC are appropriate
- Solar Vehicles
  - Require fast convergence to MPP
  - Fuzzy logic control, neural network, RCC, load current or load voltage maximization may be considered
- Residential Use
  - Partial shading issues, payback time
  - Two stage incremental conductance, current sweep methods, OCC MPPT

Applications

- Street lighting
  - Charging of batteries during the day
  - Easy and cheap implementation is more important
  - Fractional V_{OC} and/or Fractional I_{SC}

Thank you!!

Prof. Suryanarayana Doolla
Email: suryad@iitb.ac.in