Green electronics: ELEC 3202 – 3
Maximum Power Point Tracking

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Overview

1. Maximum power point
2. Maximum power point tracking technique
3. Practical example
PV Cell module and Array

• PV modules can be connected in series or in parallel to form an Array
• Parallel or series interconnection, the overall I-V curve remains the same
Generic IV curve behaviour of a PV module

- For a given I-V Characteristic (black curve)

- Increased irradiance (G) generate an increase in current.

- Increased Temperature (T) generate a worse I-V curve.
Example of Infrared thermography of a PV

- Lock-in infrared image of PV module showing non-uniform temperature distribution of module

- Lock-in infrared image of Si PV module showing delaminated region (dark encircled region) and shunts (bright region).
Example of Infrared thermography of a PV

This is a thermographic image of a solar module.

Many individual solar cells make up one solar module. The solar cells are the squares within the grid of dots on the module.

You can see the cells that are giving off a much higher heat signature. The hotter cells are not supplying energy to the grid system because they are locally dissipating their energy as heat.
PV module and PV Curve

- $P, V$ point is the power that is produced and delivered to the rest of the PV system and the load

- $P = V \times I$
PV module and PV Curve

- In order for the PV system to operate a maximum Power, I and V must operate at the maximum power point $P_{MAX}$. 

![PV module and PV Curve diagram]

$P_{MAX}$
PV module and PV Curve

• If due to illumination or temperature change the I-V curve changes, the maximum Power point (previously Pmax) will move to P'_{MPP}.

• To maintain efficiency an MPP tracker system is needed.
The maximum power point tracking (MPPT) system

- The basic principle of Maximum Power Point Tracking is to ensure that the PV system operates in its region of maximum power output from the PV cells.
- This means modulating the load from the PV Array to optimize the voltage and current to achieve this.
  - Regulate the Voltage: $V_{mpp}$
  - Regulate the current: $I_{mpp}$
Maximum power point MPPT techniques

MPPT Techniques

- Indirect
  - Fixed Voltage Method
  - Fractional Open Circuit Voltage Method
  - Perturb and Observe Method
- Direct

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The indirect fixed voltage method

What are the issues with this method?
The indirect fixed voltage method: issues

- Model suited for places with low variation of irradiance
- Not accurate
- Empirical setup
Fractional open circuit voltage method

\[ V_{mpp} = k \times V_{oc} \]

Algorithm measures open circuit voltage of the PV array and multiplies the VOC by a constant K to obtain Vmpp
Fractional open circuit voltage method:

What is the biggest issue with this method?

How to improve it?
Fractional open circuit voltage method

- To avoid the efficiency to be reduced due to the disconnection of the PV array, the Voc of a matched Pilot cell is measured instead.
- $K$ has an uncertainty

\[ V_{mpp} = k \times V_{oc} \]
MPPT- Direct perturb and observe

- Disturbance introduce in the voltage
- If decrease voltage and power decrease then increase voltage
- If increase voltage and power increase then increase voltage
- Issues with rapidly changing illumination
MPPT - incremental conductance

\[ \text{Conductance} = \frac{I}{V} \]

Current \( I \)

Voltage \( V \)

Power \( P \)

\( \frac{dP}{dV} > 0 \)

\( \frac{dP}{dV} < 0 \)

\( dP = 0 \)

\( I_{SC} \)

\( V_{OC} \)

\( I_{mpp} \)

\( V_{mpp} \)
MPPT - incremental conductance

\[
\frac{dP}{dV} = \frac{d(I \times V)}{dV} = I + \frac{V \times dI}{dV}
\]

For small increments of \(dI\) and \(dV\)

\[
\frac{\Delta I}{\Delta V} = -\frac{I}{V}
\]

At MPP

\[
\frac{\Delta I}{\Delta V} > -\frac{I}{V}
\]

To the left of MPP

\[
\frac{\Delta I}{\Delta V} < -\frac{I}{V}
\]

To the right of MPP
MPPT- incremental conductance algorithm

\[ \Delta I = I_t - I_{t-1} \]
\[ \Delta V = V_t - V_{t-1} \]

Vref is the voltage forced by the MPPT

V(t) and V(i) are the PV measured current and voltage
MPPT- incremental conductance

- Rapid response time to illumination variation
- More complex circuits
  - Real time reading of V and I
  - Real time comparison of $\frac{\Delta I}{\Delta V}$
Practical example

• If we consider a PV array, where a number of cells are connected together, then the nominal voltage will be usually 12V or 24V
Practical example: Direct Connection to battery

• If we simply connect the PV array to a battery, and it needs to be charged, then the PV array will automatically operate at the battery voltage (say 12V)

• However, looking at the IV curves, this will be not at the maximum power point level, and so the power achievable for this module will only be 53W (at point A)
Practical example: Using an MPPT

• If, however, we introduce a maximum power point tracker, we can modulate the voltage required from the PV panel, and move the voltage to 17V (point B)

• This will give a power output of nearly 75W, which is nearly 42% more power than the unregulated approach
Practical example: MPPT Architecture
Practical example: How does the MPPT work

• The MPPT is a DC/DC Converter which converts the input voltage to the correct battery voltage
• The input voltage range of the MPPT will match closely the expected range of the PV array output, say in the range 3V to 20V
• The output voltage (nominal) will be matched to the battery storage system (say 12V or 24V)
Practical example: Boost Converter

• The main power converter is often a Boost converter, so called because it boosts the voltage output to a value greater than the input.
• This technique allows the duty cycle of the PWM controller to be modulated to manage the output voltage.
• This is especially appropriate where we would use a PV array where the normal open circuit voltage (up to 17V) is lower than the battery voltage (24V).
Practical example: Boost Converter

- The boost converter has a series inductance and a parallel switch.

![Boost Converter Diagram]

- The basic equation for the voltage ratio of the converter is:
  \[ \frac{V_o}{V_i} = \frac{1}{1 - D} \]
Practical example: Boost Converter
Practical example: Normal Boost Supply

- In a standard boost converter, we would simply be matching the load voltage (24V) requirements to the input available voltage using the duty cycle (D)

- So, for example, if the PV Panel was operating at 10V, then to achieve an output of 24V, the duty cycle would be 0.583
Practical example: Including the MPPT function

- In order to maximise the power, however, we need to monitor the input voltage and current of the PV array, and ensure that the current drawn through the load is then matched with the correct current from the PV array to maximise the power.
Practical example: Dither Algorithm

• It is clearly difficult to establish for all panels what the maximum power point is

• It is also a problem if this is “hard coded” into a controller

• As discussed previously, the usual technique is therefore to measure the power and then “dither” the duty cycle (meant to introduce perturbation) to establish whether the power has increased or decreased as a result.
Practical example: Dither Algorithm

• The algorithm can easily be implemented in a simple microcontroller, in conjunction with a basic boost converter, with the algorithm of the following form:

  1. Measure Power
  2. Dither Duty Cycle
  3. Measure Power
  4. Adjust Duty Cycle

Check direction and adjust accordingly.
Practical example: Over Voltage Protection

• In addition to the dither routine, the MPPT controller can also reduce the losses in the system.
• This can be done by ensuring that the voltage is not too high when the battery has been charged.
• This will reduce the current, even when the system moves off the maximum power point, to ensure that the PV array does not overheat.
Practical example: Industry chip based solutions

- http://www.linear.com/solutions/1049
Conclusion

• Maximum power point tracking is an essential aspect of modern PV systems design

• The improvement in efficiency can be typically between 15 and 30%, although a theoretical maximum of over 40% can be achieved under certain conditions