A Switched Extremum Seeking Approach to Maximum Power Point Tracking in Photovoltaic Systems

Scott J. Moura
Grid Integration of Alternative Energy Sources – Professor Ian Hiskens

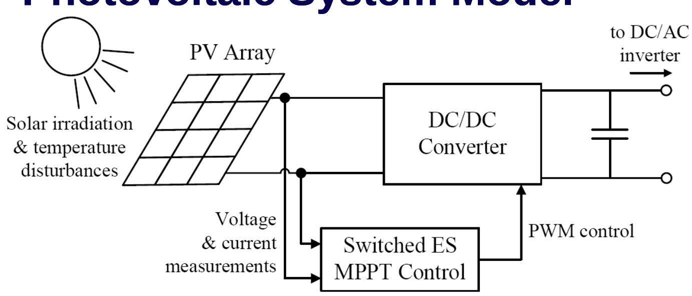
Motivation

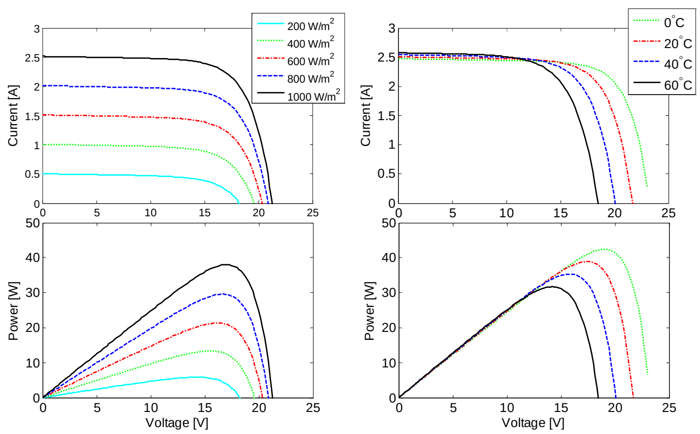
- Increase energy conversion efficiency
- Mathematically guarantee asymptotic convergence, eliminate limit cycles
- Use control theoretic techniques and models developed in class

New Contributions

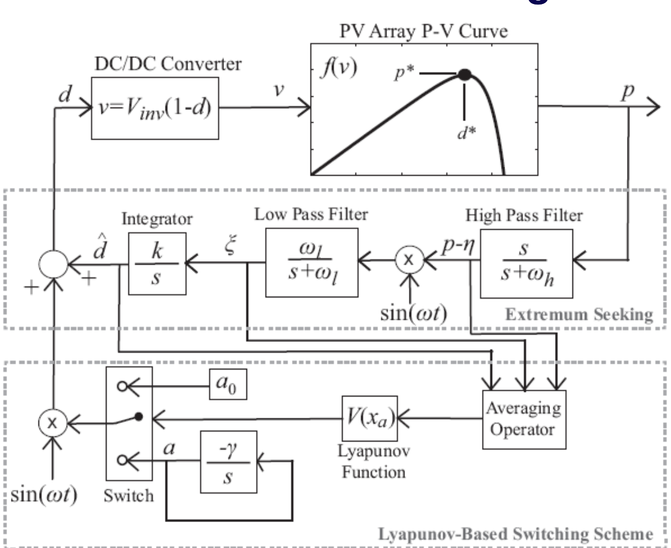
- Examine extremum seeking (ES) methods for MPPT
- Apply a switching scheme that enables asymptotic convergence

Photovoltaic System Model





Switched Extremum Seeking



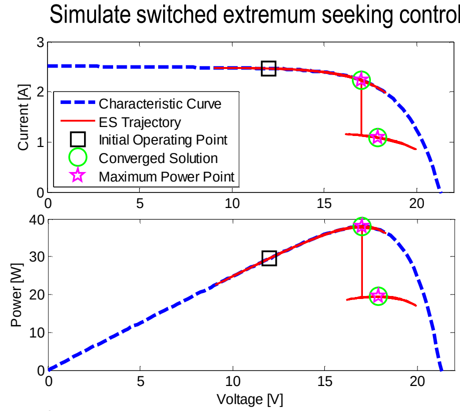
Lyapunov-Based Switching Scheme

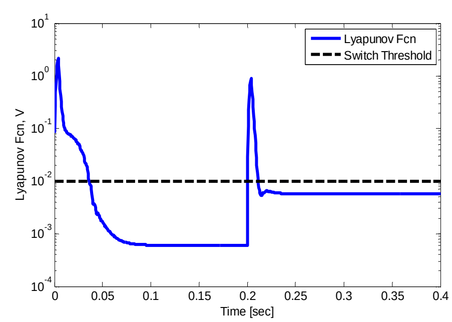
- Use stability proof by Krstic and Wang, *Automatica*, 2000.
  - Compute the average system: $x_a = 1/T \int_T x(\tau)d\tau$
  - Linearize the averaged system about the extremum point: $A = [df_a/dx_a]_{eq}$
  - Show the Jacobian A is Hurwitz: $\mathrm{Re}[\mathrm{eig}(A)] < 0$
- Develop a Lyapunov function to track proximity to the extremum point
  - Use the Jacobian A to solve the following Lyapunov equation: $PA + A^TP = -Q,\ Q>0$
  - Pose a quadratic Lyapunov function: $V(x_a) = 1/2 \cdot x_a^T P x_a$
  - Switched duty ratio controller for DC/DC converter
  - Perturbation amplitude decays exponentially

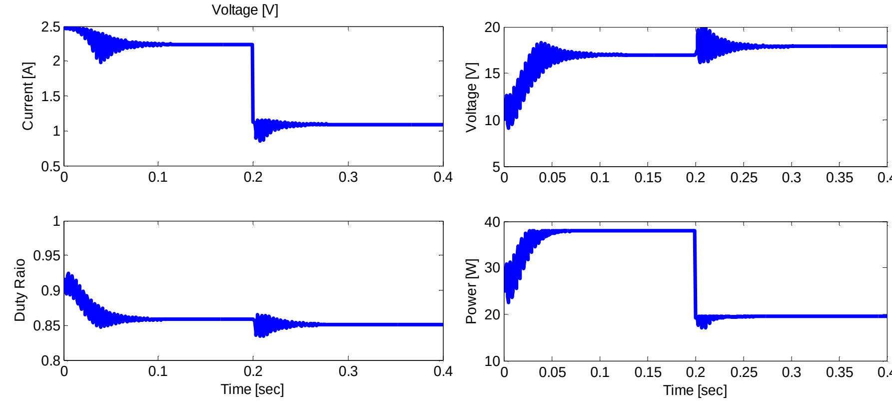
$$d(t) = \begin{cases} \hat{d} + a_0 \sin(\omega t) & \text{if } V(x_a) > \epsilon \\ \begin{cases} \hat{d} + a \sin(\omega t) \\ \frac{da(t)}{dt} = -\gamma a(t) \quad a(0) = a_0 \end{cases} & \text{otherwise} \end{cases}$$

Impact of Varying Environmental Conditions

Simulate switched extremum seeking controller for **1000 W/m²** to **500 W/m²** step change in incident **solar irradiation** at 200 ms







Conclusions

- Extremum seeking **provably** converges to the maximum power point
- Switched Lyapunov scheme allows **asymptotic convergence**
  - *Uses averaging and Lyapunov stability theory*
  - *Independent of specific PV array*
  - *Does not require periodic tuning*
  - *Requires only the existing voltage and current sensors*

Future Work

- Investigate impact of shading effects
- Prove stability of switched system
- Investigate alternative perturbation signals (e.g. square, triangle, stochastic)
- Implement and analyze proposed algorithm on an experimental setup