An Improvement of Incremental Conductance MPPT Algorithm for PV Systems Based on the Nelder–Mead Optimization

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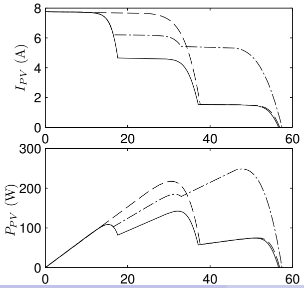
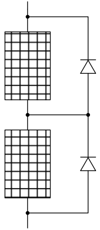
Presentation Outline

- Introduction
- General Maximum Power Point Tracking System
- PV Model
- Convex Properties of PV P–V curve
- Nelder–Mead Algorithm for MPPT
- Simulation Experiments
- Conclusion

Introduction

- Need for maximum power production from PV systems
- Soft computing methods are based on:
  - PV system physical characteristics - P&O, IC, HC, constant voltage, constant current
  - Control theory - extremal control, sliding mode, neural networks, fuzzy logic
  - Optimization algorithms - genetic algorithms, differential evolution, particle swarm optimization, Nelder–Mead
- Partial shading - one global maximum on static P–V curve



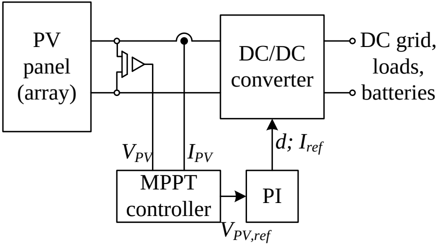


Introduction

- Common MPPT system with partial shading feature consists of two parts
  - One algorithm for uniform irradiance conditions - P&O, IC
  - Dedicated algorithm for global search
- With Nelder–Mead only one part is needed

Maximum power point tracking system

- Optimization variable - duty cycle, referent inductor current, PV voltage, PV current
- Optimization is one dimensional parameter space - PV voltage
- Dedicated, inner PV voltage controller - disturbance rejection, larger loop bandwidth - faster sample times of the MPPT algorithm



Conventional PV system with MPPT controller.

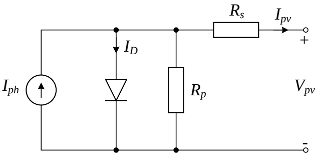
PV model

- One-diode model

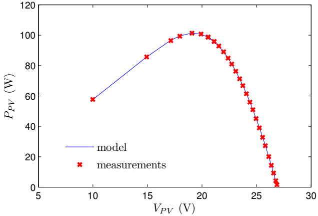
$$I_{pv} = I_{ph} - I_0 \left[\exp\left(\frac{q\,(V_{pv} + I_{pv} R_s)}{A_k\, k\, T_c\, n_s} \right) - 1 \right] - \frac{U_{pv} + I_{pv} \cdot R_s}{R_p}, \quad (1)$$

$$I_{ph} = \frac{G}{G_{ref}} \left[I_{ph,ref} + \mu_{I,sc} \left(T_c - T_{c,ref} \right) \right], \quad (2)$$

$$I_0 = I_{0,ref} \left(\frac{T_c}{T_{c,ref}} \right)^3 \exp\left[\frac{qE}{kA_k} \left(\frac{1}{T_{c,ref}} - \frac{1}{T_c} \right) \right], \quad (3)$$



Electrical schematic of a PV panel.



Static P-V curve.

Convex properties of PV P–V curve

Theorem (Lagarias et al., 1998)

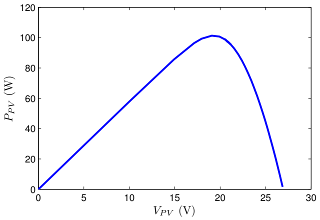
In dimension 1, The Generic Nelder–Mead method converges to the minimizer of a strictly convex function with bounded level sets if and only if the expansion step is a genuine expansion (i.e. if $\alpha_r \alpha_e \geq 1$).

Definition

If f is twice differentiable (i.e. $f \in C^2$), then $f(x)$ is strictly concave if $f''(x) < 0$.

- Actualy static P-V curve is strictly concave in the interval $V_{PV} \in [0, V_{oc}]$:

$$\frac{d^2 P_{PV}}{dV_{PV}^2} \leq M < 0 \qquad (4)$$



Nelder–Mead algorithm

- Class of *direct search methods* - derivative free method
- Unconstrained optimization of real valued function $f(\mathbf{x}) : \mathbb{R}^n \to \mathbb{R}$
- Algorithm flow:
  - Simplex based method - simplex size 2
  - Each point in simplex (vertex v) has associated function value $f(v)$
  - After each iteration vertices are sorted
  - Vertex with *maxf* (v) becomes *centroid*
  - New vertex is calculated around centroid which replaces worst vertex using 5 transforms: reflexion (α_r), expansion (α_e), outside or inside contraction (α_c), and shrinkage (α_s)

Nelder–Mead Algorithm - Properties 1/2

- Algorithm works in two modes of operation
  - Local search: under uniform irradiation
  - Global search: under partial shading
- The parameters α_r and α_e are the same in both modes
- The parameters α_c and α_s are different - closer to 1 in global search
- Criteria for global search: $|P_k - P_s| \geq \lambda P_s$
- Initial simplex is set differently in two modes:
  - Local:

$$v(1) = V_{PV}[k]$$
$$v(2) = 1.05 v(1)$$

  - Global:

$$v(1) = V_{min}$$
$$v(2) = 0.8 V_{max}$$

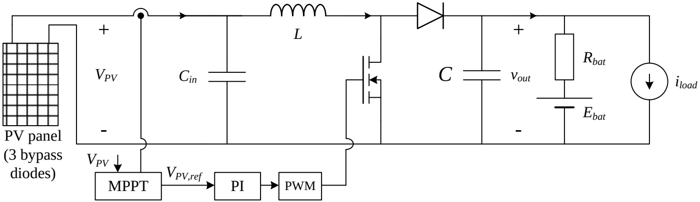
Nelder–Mead Algorithm - Properties 2/2

- Criteria to stop search - Incremental Conductance

$$\frac{dP_{PV}}{dV_{PV}} = 0 \Rightarrow I_{PV} + V_{PV}\frac{\partial I_{PV}}{\partial V_{PV}} = 0,$$
$$tol = I_{PV} + V_{PV}\frac{\partial I_{PV}}{\partial V_{PV}},$$
$$|tol| \leq \varepsilon.$$

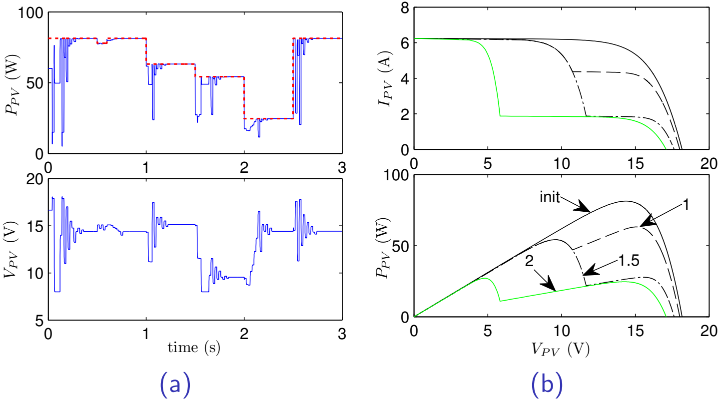
Simulation experiments

- Simulations were carried out in Matlab/Simulink
  1. Synthetic test for certain scenarios - local and global search
  2. Test with real measured irradiance and temperature profiles (Kipp&Zonen CMP11 pyranometer for global irradiance, and PT100 sensor for temperature; 27th April 2013) - only local search
- Parameter values: $\alpha_r = 1$, $\alpha_e = 2$, $\alpha_c = 0.5$, $\alpha_s = 0.5\,(0.5)$

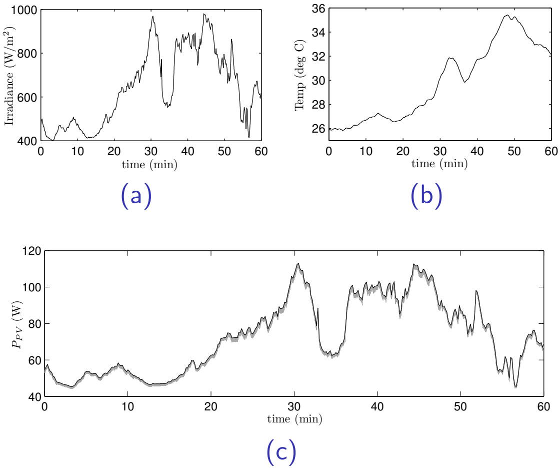


PV system under investigation

Simulation experiments - Test 1



Test 1 - (a) Responses of the PV power and voltage. Maximum theoretical power is marked with dashed red line; (b) Static power curves for various conditions. Solid black - initial conditions, dashed - $t = 1$ s, dot-dashed - $t = 1.5$ s, green solid - $t = 2$ s.



Test 2 - (a) Irradiance profile, (b) temperature profile and (c) extracted power in gray, and maximum theoretical power in black.

Conclusion

- Improvement of the well-known IC MPPT algorithm by using Nelder-Mead optimization algorithm
- The performance of the algorithm under uniform insolation and partial shading was tested
- The proposed algorithm accurately tracks global maximums under both conditions
- In the future work we will be focusing on better partial shading determination, on experimental testing of the proposed algorithm on various PV configurations, and on experimental comparison with other MPPT solutions

Thank you for your attention!

Acknowledgment

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