Irradiance Estimation for a Smart PV Array

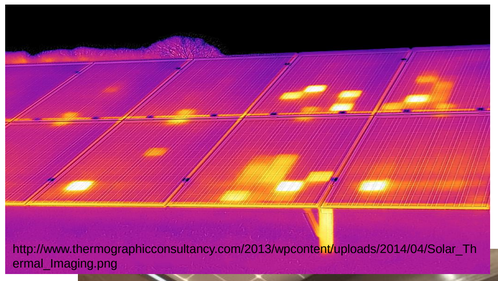
Henry Braun, Shwetang Peshin, Andreas Spanias, Cihan Tepedelenlioglu, Mahesh Banavar, Girish Kalyanasundaram and Devarajan Srinivasan

SenSIP Center, School of ECEE, Arizona State University, Tempe, AZ

The Problem

Data collected at inverter leaves unanswered questions:

- Are PV modules performing to spec?
- Does the array need cleaning?
- Are there significant mismatch losses?
- Is there a fault in the array?



http://www.thermographicconsultancy.com/2013/wpcontent/uploads/2014/04/Solar_Thermal_Imaging.png

Inefficiencies:

- Partial shading
- Long mean time to repair

Our Solution

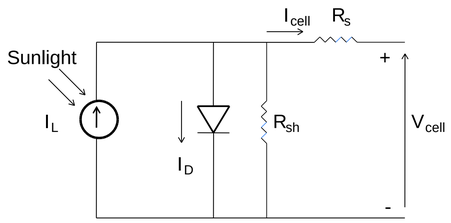
- Smart monitoring devices deployed at the level of individual modules
- Topology reconfiguration via switching

- Fault detection
- Data visualization and performance metrics
- Mitigate losses due to partial shading and other mismatch conditions

Irradiance Estimation Algorithm

- Estimate Single-diode model irradiance from current, voltage, and temperature:

$$S = S_{ref}\left(\frac{I + I_0\left(\exp\left[\frac{V+IR_s}{a}\right]-1\right)}{f_1(M)\left[\alpha_{I_{SC}}(T_C - T_{c,ref})\right] - \frac{V+IR_s}{R_{sh,ref}}}\right)$$



Single-diode model

Propagation of error calculation

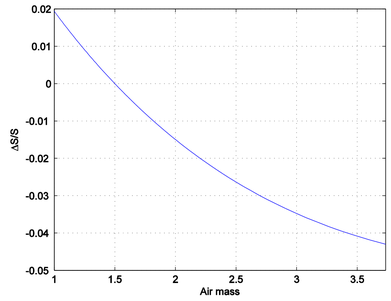
$$\frac{\partial}{\partial T_c}\left(\frac{S}{S_{ref}}\right) = \frac{I_0\left[\exp\left[\frac{(V+IR_s)q}{N_s n_1 k_b T_c}\right]\left(\frac{3T_c^2}{T_{c,ref}^3} - \frac{(V+IR_s)q}{N_s n_1 k_b T_c^2} + \frac{E_g}{T_c^2}\frac{q}{k_b}\right) - \frac{E_g}{T_c^2}\frac{q}{k_b}\right]}{f_1(M)\left[\alpha_{I_{SC}}(T_c - T_{c,ref})\right] - \frac{V+IR_s}{R_{sh,ref}}} - \frac{\left[I + I_0\left(\exp\left[\frac{(V+IR_s)q}{N_s n_1 k_b T_c}\right]-1\right)\right] f_1(M)\alpha_{I_{SC}}}{\left[f_1(M)\left[\alpha_{I_{SC}}(T_c - T_{c,ref})\right] - \frac{V+IR_s}{R_{sh,ref}}\right]^2}$$

$$\frac{\partial}{\partial I}\left(\frac{S}{S_{ref}}\right) = \frac{1 + I_0\frac{R_s}{a}\exp\left[\frac{(V+IR_s)}{a}\right]}{f_1(M)\left[\alpha_{I_{SC}}(T_C - T_{c,ref})\right] - \frac{V+IR_s}{R_{sh,ref}}} - \frac{R_s/R_{sh,ref}\left[I + I_0\left(\exp\left[\frac{(V+IR_s)}{a}\right]-1\right)\right]}{\left[f_1(M)\left[\alpha_{I_{SC}}(T_C - T_{c,ref})\right] - \frac{V+IR_s}{R_{sh,ref}}\right]^2}$$

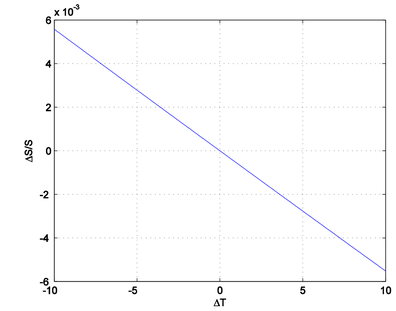
$$\frac{\partial}{\partial V}\left(\frac{S}{S_{ref}}\right) = \frac{I_0/a\exp\left[\frac{(V+IR_s)}{a}\right]}{f_1(M)\left[\alpha_{I_{SC}}(T_C - T_{c,ref})\right] - \frac{V+IR_s}{R_{sh,ref}}} - \frac{1/R_{sh,ref}\left[I + I_0\left(\exp\left[\frac{(V+IR_s)q}{N_s n_1 k_b T_c}\right]-1\right)\right]}{\left[f_1(M)\left[\alpha_{I_{SC}}(T_C - T_{c,ref})\right] - \frac{V+IR_s}{R_{sh,ref}}\right]^2}$$

Performance

- < 4% error in Irradiance for air mass < 3
- < 1% error for temperature errors < 10° C



Error due to air mass uncertainty at STC



Error due to temperature measurement uncertainty at STC

Acknowledgments

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References

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[3] S. T. Buddha, H. Braun, V. Krishnan, C. Tepedelenlioglu, A. Spanias, T. Yeider, and T. Takehara, "Signal processing for photovoltaic arrays," in Int. Conf. on Emerging Signal Processing Applications, Jan 2012.

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