Modeling and Simulation of PV Arrays in a Low Voltage DC Microgrid

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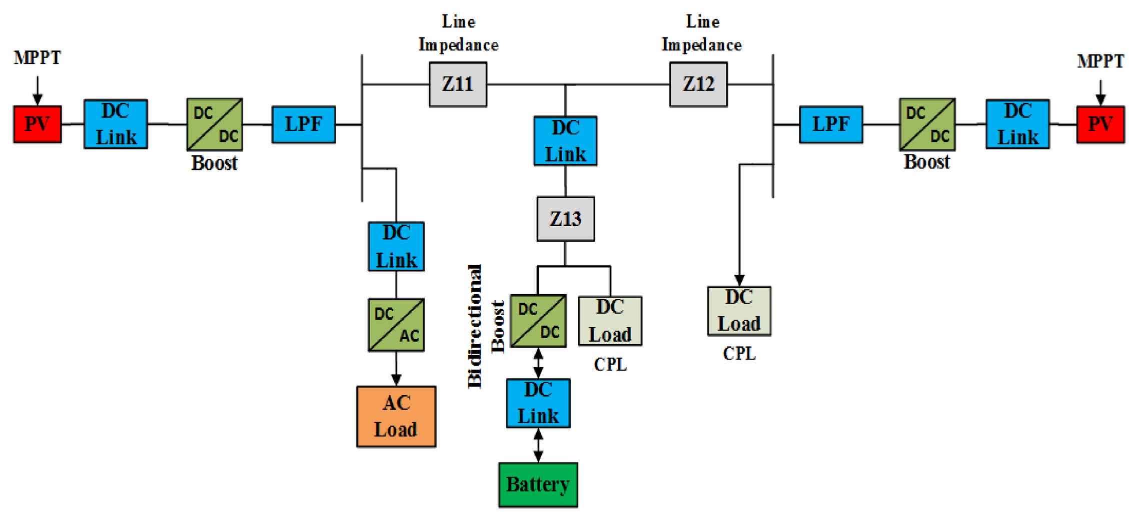

Figure 1. Standalone DC Microgrid Structure

Introduction

➢ **What is a DC Microgrid?**

Localized dc sources providing electricity through dc transmission to ac and/or dc loads operating in grid connected or disconnected (standalone) mode.

➢ **What are PV Arrays?**

Photovoltaic (PV) cells are devices which convert light energy to electrical energy. They can be connected together in series forming a module to achieve higher voltage. Modules connected in parallel to achieve higher current form an array.

➢ **Why model?**

Variance in the suns supply requires modeling of the cell to find ways to extract maximum power from the sun throughout the day.

➢ **What is Maximum Power Point Tracking?**

MPPT is the use of a power converter to interface to the array to the load in order to force the voltage to the maximum power point.

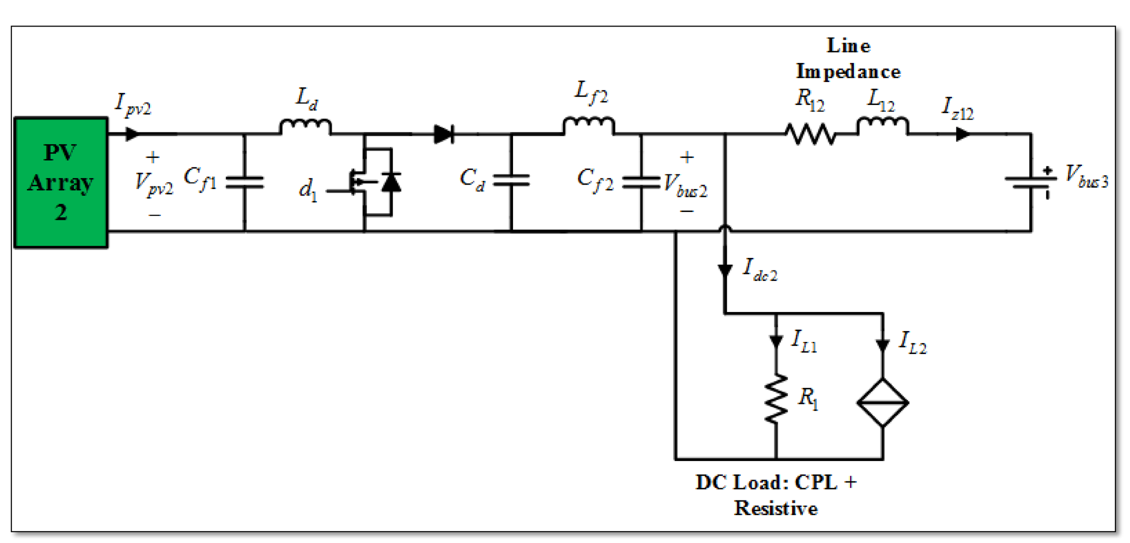

Figure 2. PV Array System With DC Load

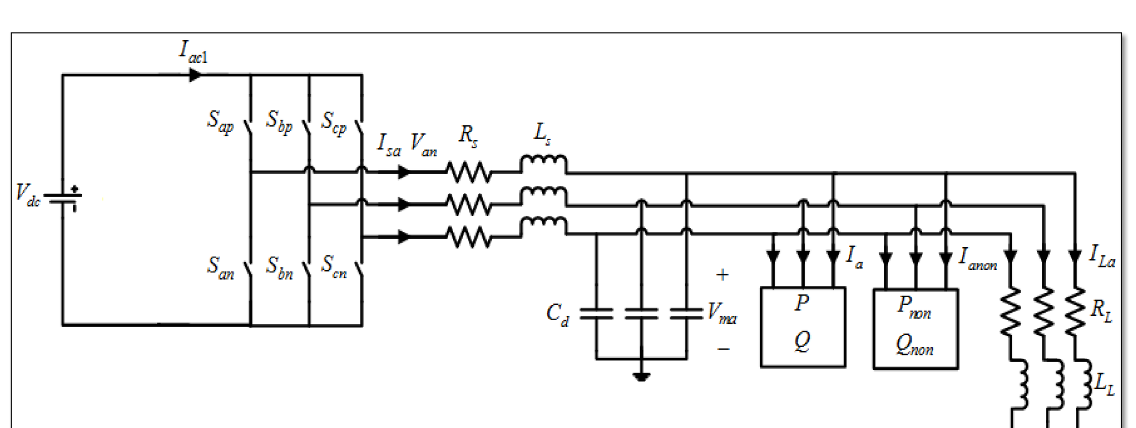

Figure 3. AC Load Connected to PV System

System Model Equations

Source

$$(1)\ I_{pv} = n_p(I_{src} + k_T(T - T_R))\frac{S}{S_n} - n_p I_{rs}\left(e^{\frac{q(V_{pv} - I_{pv}R_s)}{KTAn_s}} - 1\right) - \frac{V_{pv} - I_{pv}R_s}{R_p}$$

Boost Converter with Low-Pass Filter

$$(2)\ C_{f1}\frac{d}{dt}V_{cf1} = I_{pv} - I_{Ld}$$

$$(3)\ L_d\frac{d}{dt}I_{Ld} = V_{pv} - S_2V_{cd}$$

$$(4)\ C_o\frac{d}{dt}V_{cd} = S_sI_{Ld} - I_{Lf2}$$

$$(5)\ L_{f2}\frac{d}{dt}I_{Lf2} = V_{cd} - V_{bus2}$$

$$(6)\ C_{f2}\frac{d}{dt}V_{bus2} = I_{Lf2} - I_{out}$$

DC and AC Loads

$$(7)\ I_{out\_dc} = I_{dc2} = \frac{V_{bus2}}{R_1} + \frac{P_{nominal}}{V_{bus2}}$$

$$(8)\ I_{out\_ac} = I_{ac1} = S_{ap}I_a + S_{bp}I_b + S_{cp}I_c$$

MPP Voltage (V)	72.9	Maximum Power (W)	435
MPP Current (A)	5.97	Series Cells	128
Open-Circuit Voltage (V)	85.6	Cell Efficiency (%)	22.5
Short-Circuit Current (A)	6.43	Panel Efficiency (%)	20.5

Table 1. SUNPOWER E20/435 PV Module

Results

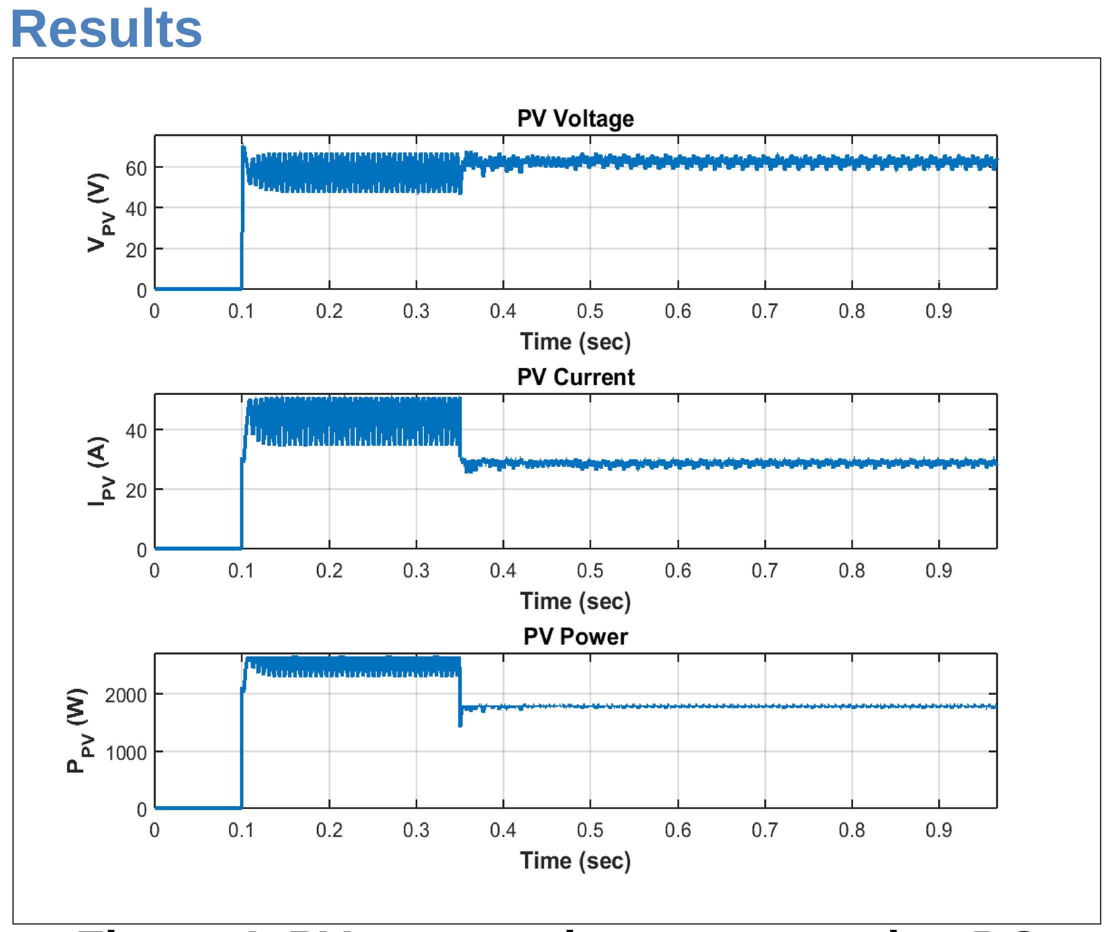

Figure 4. PV output when connected to DC CPL with 8 modules in parallel and duty cycle step size of 0.5 %

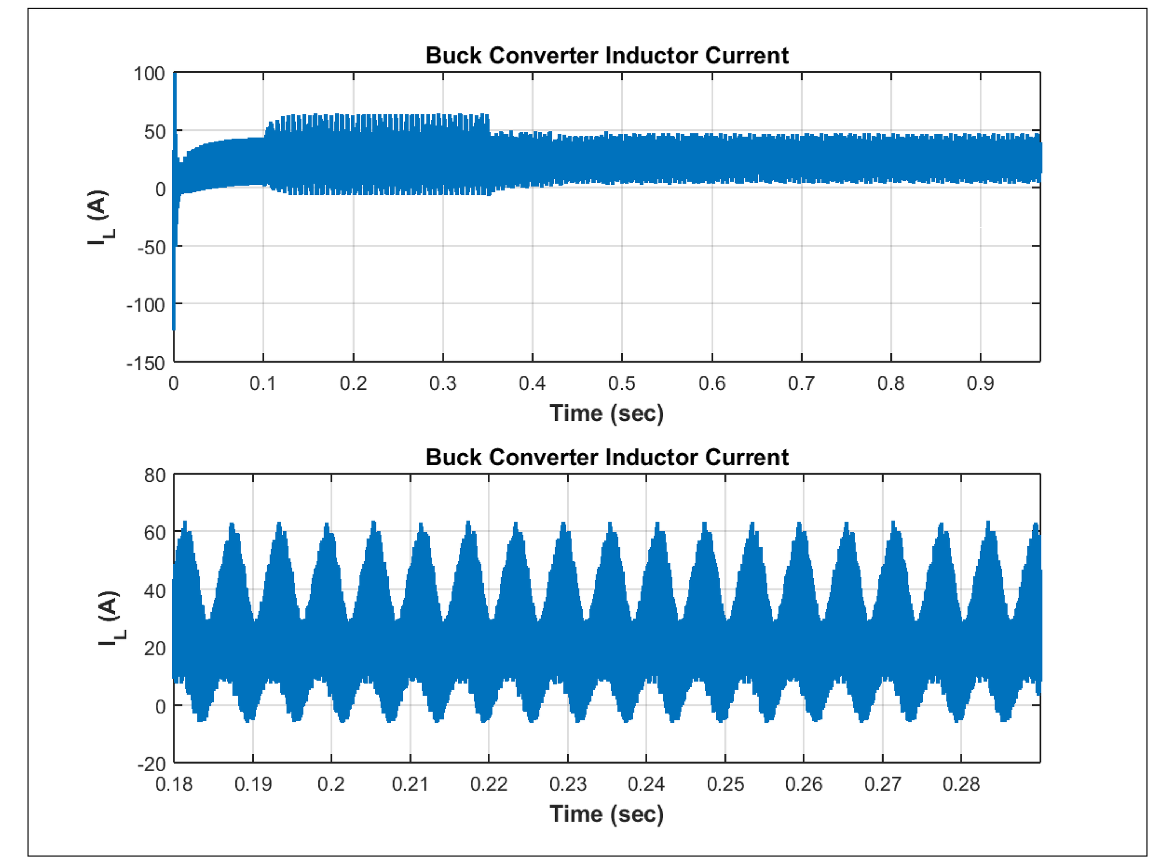

Figure 5. Boost Converter Output Current (DC Load Input Current)

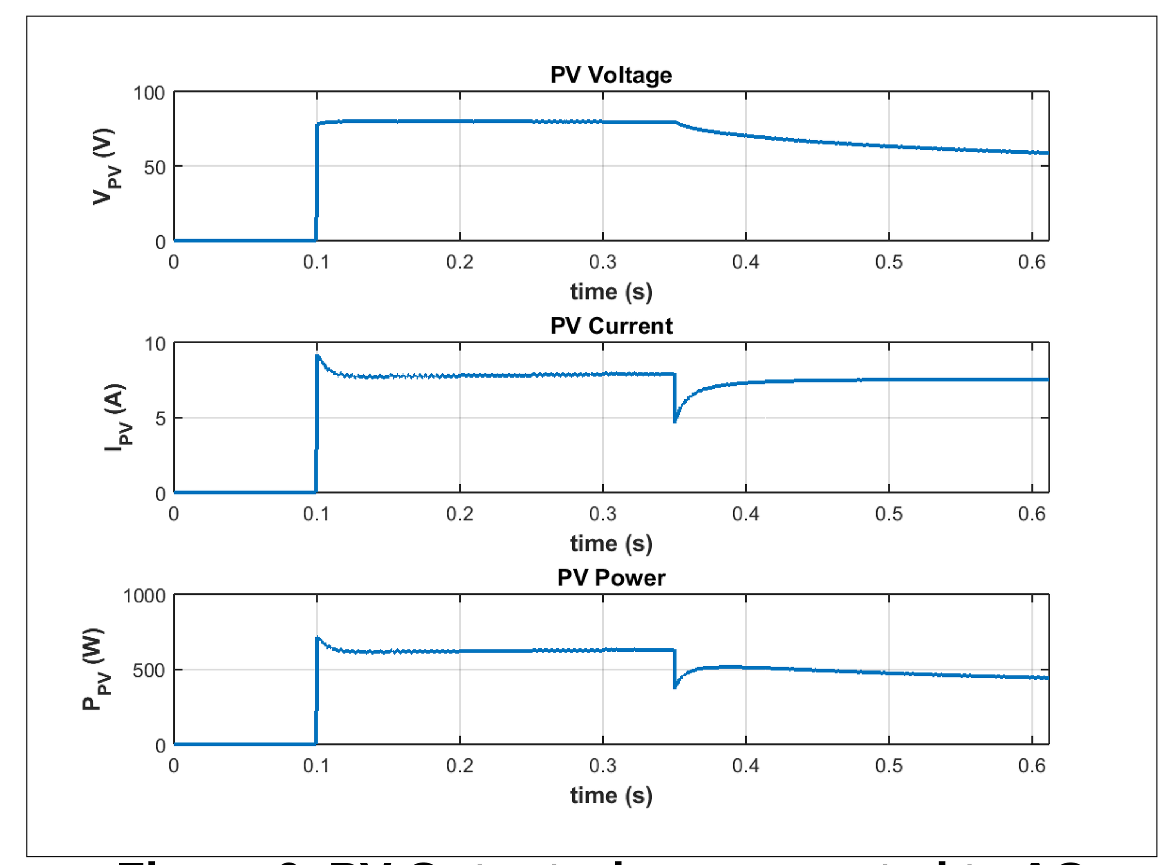

Figure 6. PV Output when connected to AC Load with 2 modules in parallel and duty cycle step size of 0.5 %

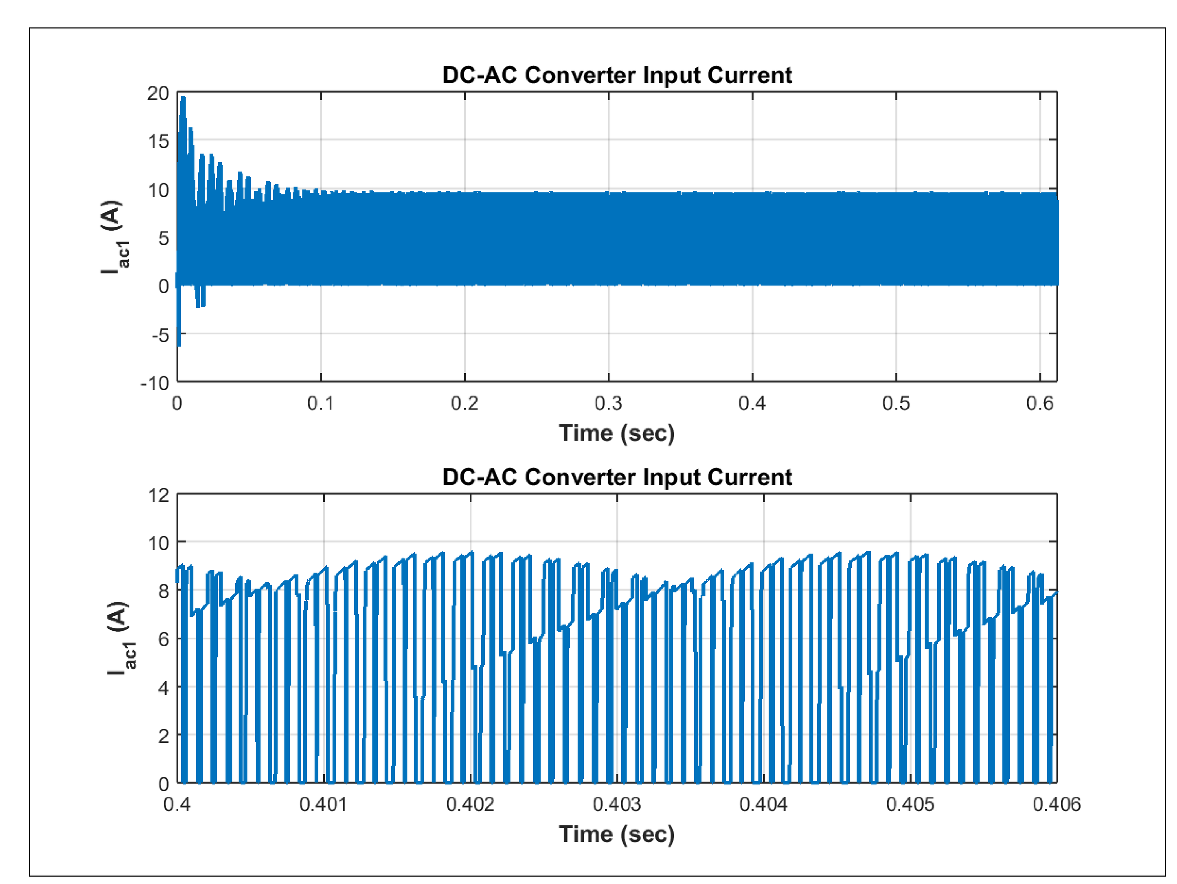

Figure 7. Boost Converter Output Current (AC Load Input Current)

Discussion

- ➢ Simulations were performed using direct duty cycle control with the incremental conductance maximum power point tracking technique.
- ➢ Duty cycle step sizes of 5 % and 0.5% were tested to find best performance with changing environmental conditions.
- ➢ A resistive Load of 2 Ω used in the DC Load tests.
- ➢ The AC Load iss comprised of the following:
  - ➢ Constant Power Load Reactive Power 300 (VAR) and Active Power 500 (W)
  - ➢ Nonlinear Load Initial Reactive and Active Powers are 150 (VAR) and 300 (W), respectively.
  - ➢ Linear Load Inductance and Resistance are 53.1 (mH) and 10 (Ω), respectively.
  - ➢ Capacitance is 500 µF.
  - ➢ Line inductance and resistance is 5 (mH) and 0.1 (Ω).
  - ➢ Inverter Input Constant 100 V and Switching Frequency 5 kHz.
- ➢ MPPT algorithm initially tested for purely resistive load in Figure 2 before testing constant power load.
  - ➢ DC Loads were tested separately.
- ➢ Simulations were performed with and without an error tolerance in the incremental conductance algorithm to test performance.

Conclusions

- ➢ Sampling period of 50 ms vs 1 ms in the zero order hold provided less oscillations around the maximum power point.
- ➢ A duty cycle step size of 0.5 % showed the best response to changing environmental conditions when connected to nonlinear loads.
- ➢ Tolerance of 0.003 necessary to minimize oscillations without PI controller.

References

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- ➢ B. Subudhi and R. Pradhan, "A Comparative Study on Maximum Power Point Tracking Techniques for Photovoltaic Power Systems," *Sustainable Energy, IEEE Transactions on*, vol. 4, no. 1, pp.89-98., 2013.

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