CREATING DYNAMIC EQUIVALENT PV CIRCUIT MODELS WITH IMPEDANCE SPECTROSCOPY FOR ARC FAULT MODELING

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Arc Fault Frequency Propagation through PV Strings Simulated with Equivalent Dynamic PV Circuits

**Background**

**Motivation:** PV system arc faults have led to a number of rooftop fires which have caused significant property damage and threatened the safety of building occupants. In response, Article 690.11 was approved for the 2011 National Electrical Code® which requires new PV systems on or penetrating a building to include a listed arc fault protection device.

**Purpose:** Sandia National Laboratories is researching the electromagnetic phenomena of PV arcs to inform arc fault detector designers of frequency-dependent attenuation, electromagnetic noise, and radio frequency effects within PV systems.

**Propagation of arcing noise through a PV string**

![Diagram showing the propagation of arcing noise through a PV string]

**Step 1: Create Equivalent AC Circuit of a PV Module**

The equivalent dynamic circuit of a PV module [1] describes the behavior of AC signals passing through a PV module. This defines the filtering behavior of the module for ac frequencies.

\[
I_{mod} = \frac{C_p}{R_p} \left( V_{ac} - V_{PV} \right)
\]

- \( R_s \): series resistance
- \( R_o \): shunt resistance
- \( R_d(V) \): dynamic resistance of diode
- \( C_d(V) \): diffusion capacitance
- \( C_t(V) \): transition capacitance
- \( V_{ac} \): acrning AC voltage
- \( \omega \): signal frequency

**Step 2: Find Equivalent Complex Impedance**

Chenvidiya et al. [2] determined the equivalent impedance model of AC PV circuits and methods to calculate component values.

\[
Z_{PV} = \left( R_s + R_p + \frac{R_d}{(\omega R_p C_p)^2 + 1} \right) + \frac{R_d}{(\omega R_p C_p)^2 + 1}
\]

where component values are from the simplified circuit:

\[
I = \frac{C_p}{R_p} \left( V_{ac} - V_{PV} \right)
\]

**Step 3: Experimentally Obtain Circuit Component Values**

Experimental and Model Impedance for Module H

**Results**

**Module Variability and Challenges**

1. Manufacturing variability changes AC circuit component values, shown below for identical modules.
2. Circuit values are dependent on voltage and frequency, illustrated in the difference in the same PV modules for different magnitudes of injected sinusoidal voltage.
3. Equivalent circuits can only be created for dark conditions because the current would damage the instrumentation.

**Challenges Encountered**

- **Challenge:** To model the AC arcing signal on the PV string, the well-studied DC diode models were found to be inadequate.
- **Solution:** Create dynamic equivalent circuit models of PV modules.
- **Challenge:** The nonlinearities present in PV cells from irradiance, temperature, frequency and bias voltage complicate the modeling process.
- **Solution:** Develop linearized dynamic equivalent circuits for a range of PV modules to match to the experimental data.

**Conclusions**

1. The numerical simulation results match experimental frequency response data for the zero irradiance case: No attenuation from 1 Hz to 100 kHz.
2. The simulations were then expanded to situations with higher irradiance which were not capable of being directly measured: no attenuation.
3. Thus, circuit modules determined arcing frequencies in PV systems will not be attenuated prior to reaching a remotely located arc fault detector.