Evaluation Method for Arc Fault Detection Algorithms

Dwight Look College of ENGINEERING, TEXAS A&M UNIVERSITY

Stephen McConnell, Zhan Wang,
Robert S. Balog, Jay Johnson
Stephen.McConnell@tamu.edu, zhmike.wang@gmail.com,
robert.balog@ieee.org, jjohns2@sandia.gov

ELECTRICAL & COMPUTER ENGINEERING
TEXAS A&M UNIVERSITY
Renewable Energy & Advanced Power Electronics Research Laboratory
http://energy.ece.tamu.edu/reaper

Sandia National Laboratories

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Introduction

- Changes to the National Electrical Code® and emergence of UL 1699B require arc fault detectors in the DC systems of photovoltaic arrays
- Arc fault detectors have been required for years in AC systems and are well developed; DC versions are relatively new, less developed, and more expensive
- Existing arc detection methods include Fourier transform, frequency band analysis, time-domain amplitude monitoring, and analysis of electric field strength dynamics through electromagnetic sensors
- Low-cost, highly effective DC arc fault detectors must be developed to mitigate the hazards and enable the widespread adoption of photovoltaic systems

Damage resulting from an arc fault in the PV array. If left undetected, loss of life could result in addition to property damage.
http://www.greentechmedia.com/articles/read/Putting-Out-The-Solar-Panel-Fire-Threat

Problem Statement

- Designing a detection evaluation experiment with scientifically repeatable results is difficult because of the lack of predictability and control over the arc characteristics
- The main source of background electrical noise in a PV system is the power electronics (inverter, etc.)
- Different inverters have different noise signatures
- Noise signatures can vary with the operating point
- Arc fault detectors must distinguish between inverter noise and the actual occurrence of an arc

Approach

- A library of inverter noise and arc signatures was compiled from real-world measurements
- A technique to synthesize waveforms using these real-world signals was developed to enable systematic design and testing of arc fault detection methods
- A metric called the arc-signal to noise ratio was defined to quantify the ratio of arc to inverter signals

Signal Length Requirement

- Test signals must be of sufficient length to ensure that detection algorithms operate correctly during both arcing and *non-arcing* portions of the signal
- An arc may appear and disappear in microseconds or sustain for a much longer duration
- Duration of replay should be from seconds to endless

Signal Extension Method

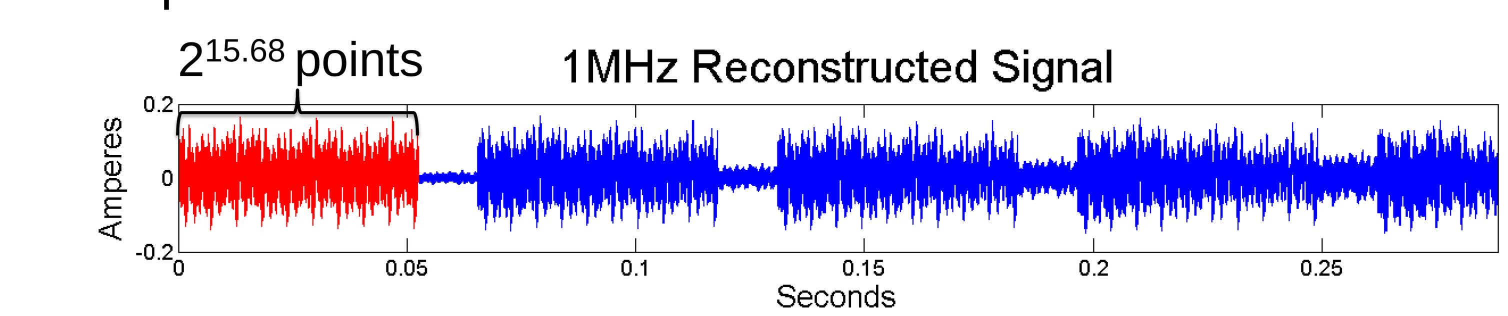
- The complex frequency components of the Fourier half-spectrum of the inverter noise signature are used to reconstruct a time-domain signal:

$$y[n] = \sum_{m=0}^{NFFT/2} X[m]\cos\left(2\pi\frac{m\cdot n}{N} + \varphi[m]\right) \qquad [1]$$

where $X[m]$ and $\varphi[m]$ are the magnitude and phase of the FFT result at the m^{th} frequency bin and $y[n]$ is the output

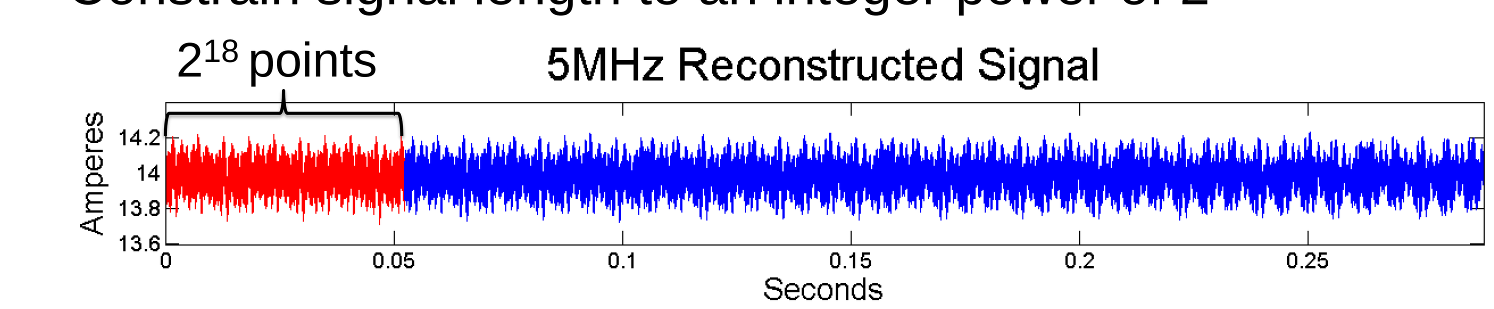
Signal Extension Challenges

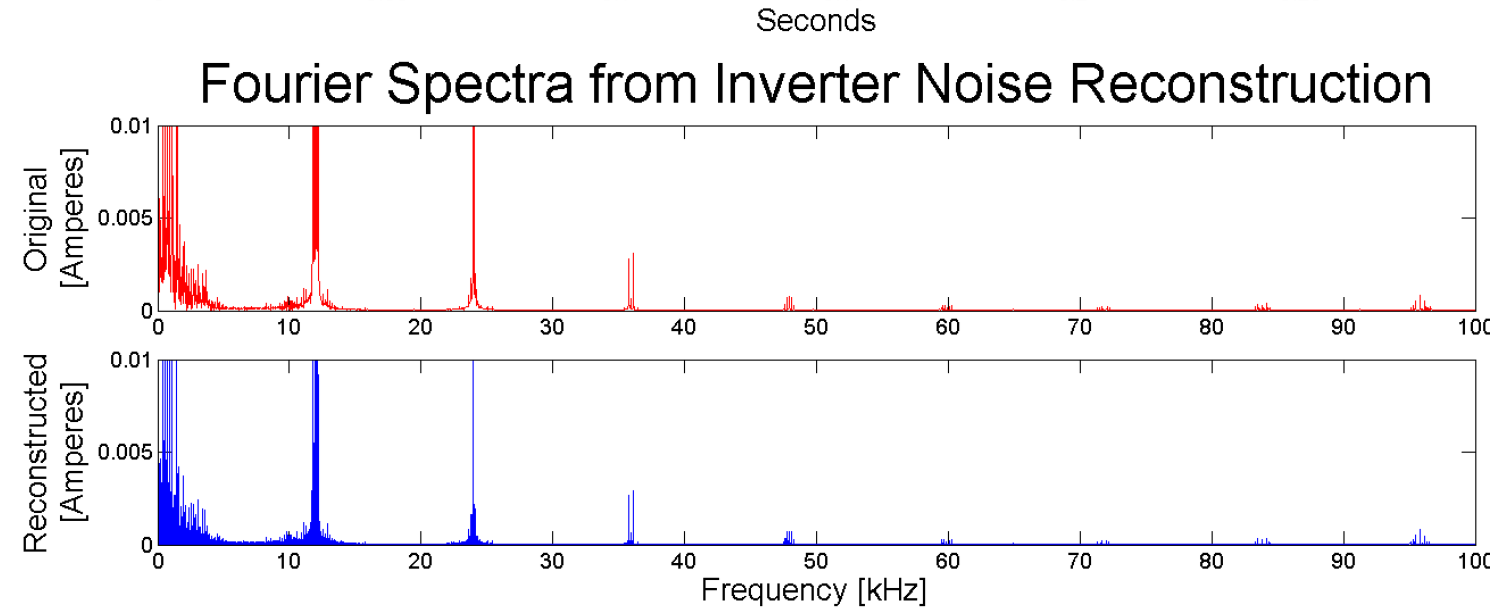
- Radix-2 FFT requires integer powers of two signal lengths
- Zero-padding is used when the number of samples, N, is less than the next largest power of two
- Signal expansion involves evaluating [1] for $n > N$
- After reconstruction, "gaps" appear in the time-domain waveform at multiples of the original signal duration (N/f_s)
- The convergence requirement for the Fourier series is in general impossible to satisfy for all frequencies in a signal composed of an arbitrary number of non-harmonic frequencies

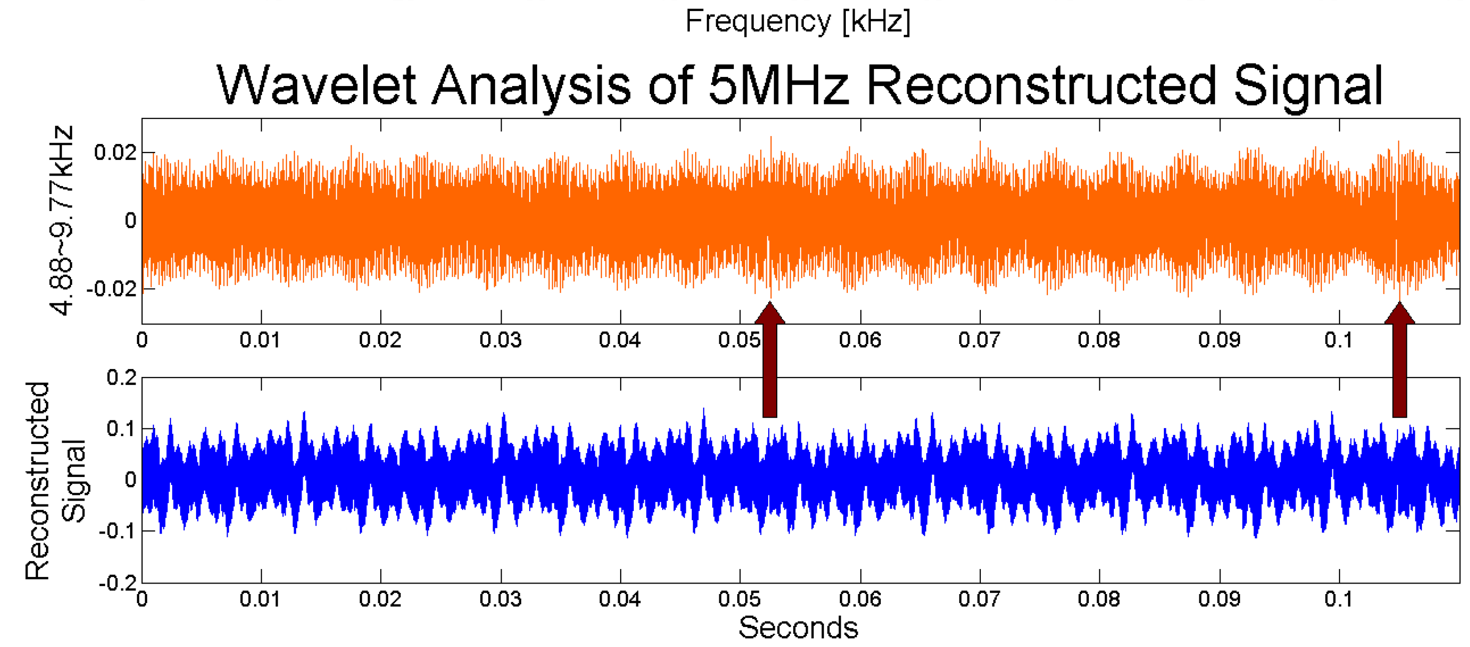


Signal Extension Solution

- Constrain signal length to an integer power of 2





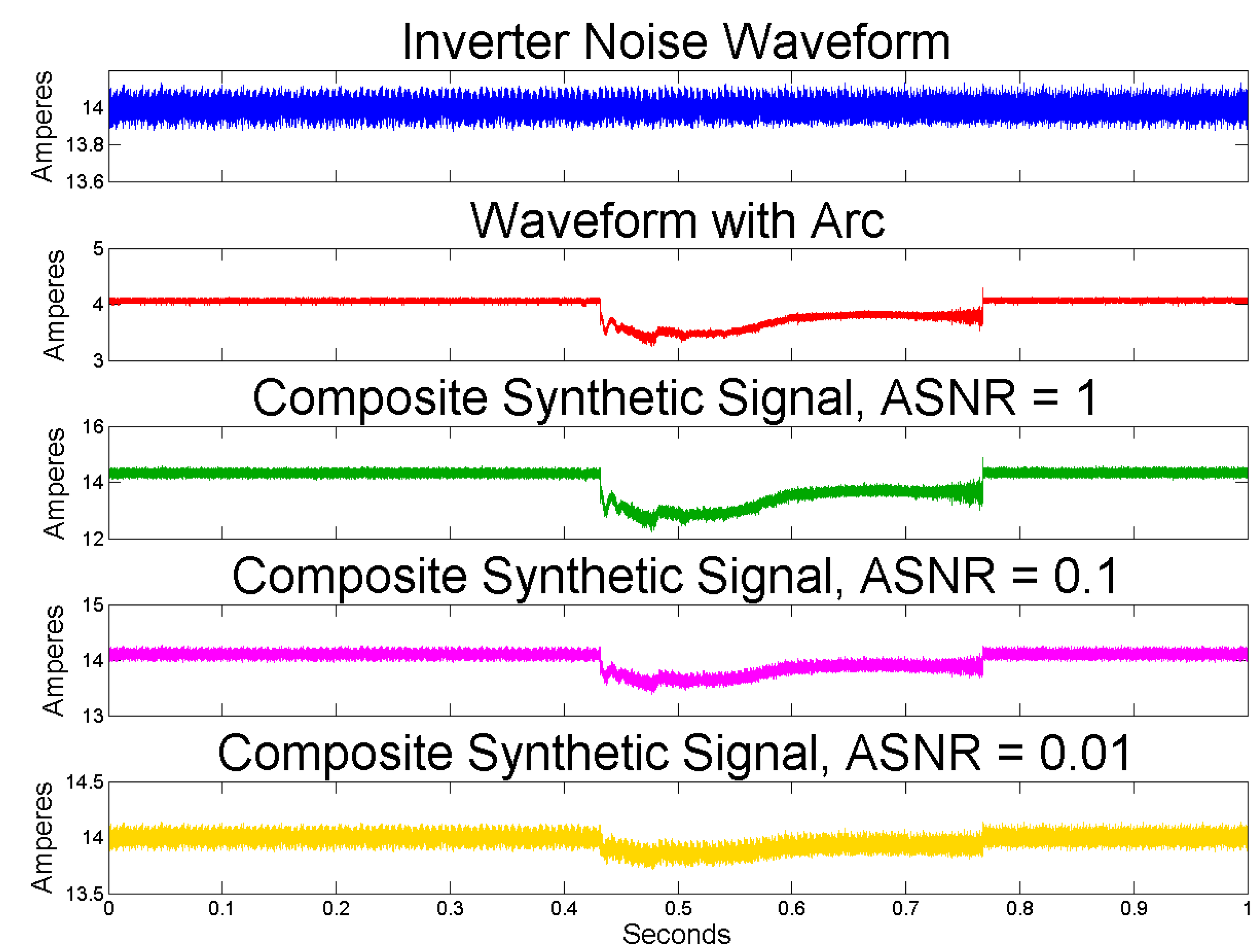


Adding the Arc

- An **A**rc-**S**ignal to **N**oise **R**atio describes the relative power magnitudes of arc and background inverter noise:

$$ASNR = \frac{P_{arc}}{P_{noise}} \qquad [2]$$

- Knowing the relative strength of one signal versus the other allows one to explore the detection limits and therefore detection capability offered by a given algorithm



Summary

- We used signal-extension, modification of sampling rates, and combination of arcing signal with background inverter noise to create test signals from real-world data
- These signals can be fed to digital algorithms providing computer simulation of results
- The test signals can also be recreated in hardware for more thorough testing of arc fault-detecting microcontroller prototypes