SAND2017-6388C

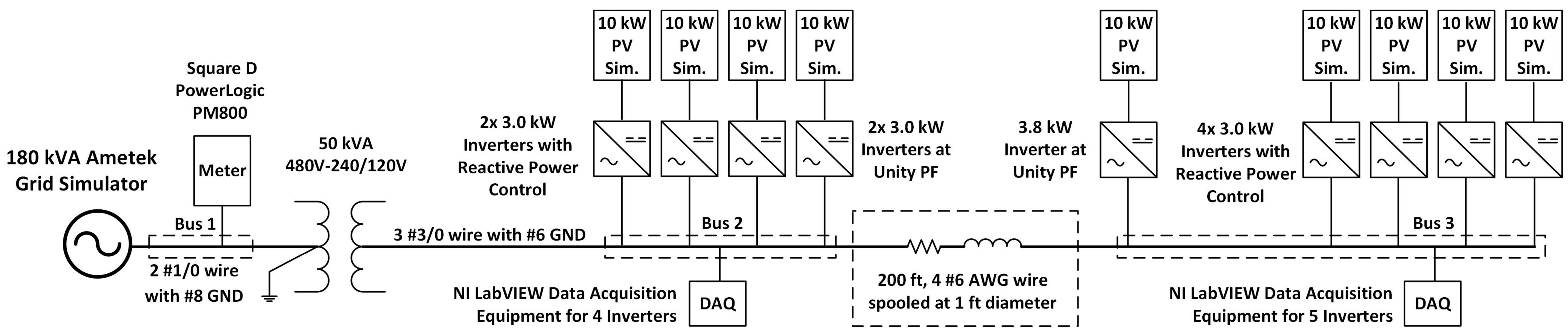
Experimental Distribution Circuit Voltage Regulation using DER Power Factor, Volt-Var, and Extremum Seeking Control Methods

Jay Johnson, Sigifredo Gonzalez - Sandia National Laboratories
Daniel B. Arnold - Lawrence Berkeley National Laboratory

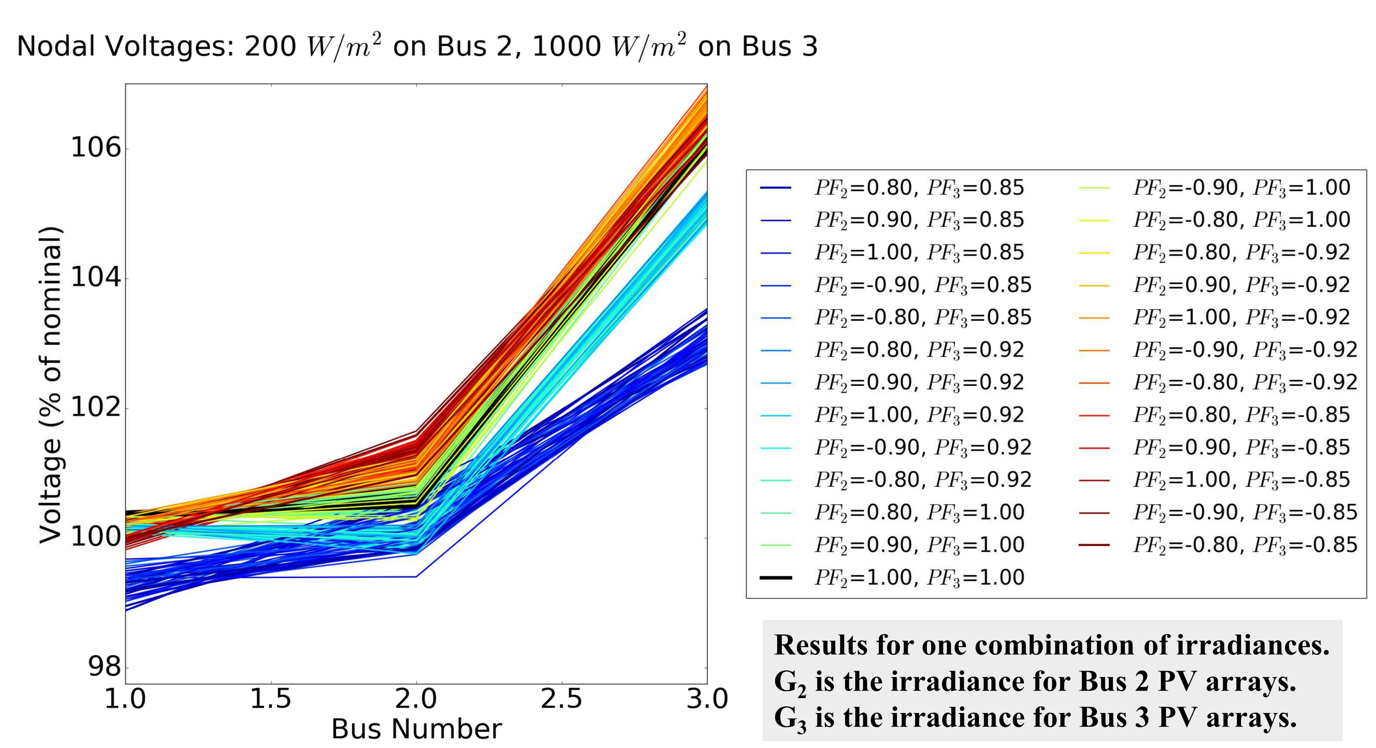
Motivation

PV inverters have the capability to minimize distribution losses and provide voltage regulation with grid-support functions such as volt-var and fixed power factor. DER reactive power function settings for specific distribution topologies have been widely studied but optimal selection of the DER operating mode and settings depends on *a priori* knowledge of system topology, DER sizes and locations, and renewable energy power generation or forecasts. Here, we experimentally evaluate an approach for optimal reactive power compensation that does not rely on power system or DER information. Specifically, we study the ability of extremum seeking (ES) control—a decentralized, model-free control strategy—to minimize distribution losses and maintain voltage limits in a laboratory environment.

Implemented 3 voltage regulation techniques on a distribution circuit replica

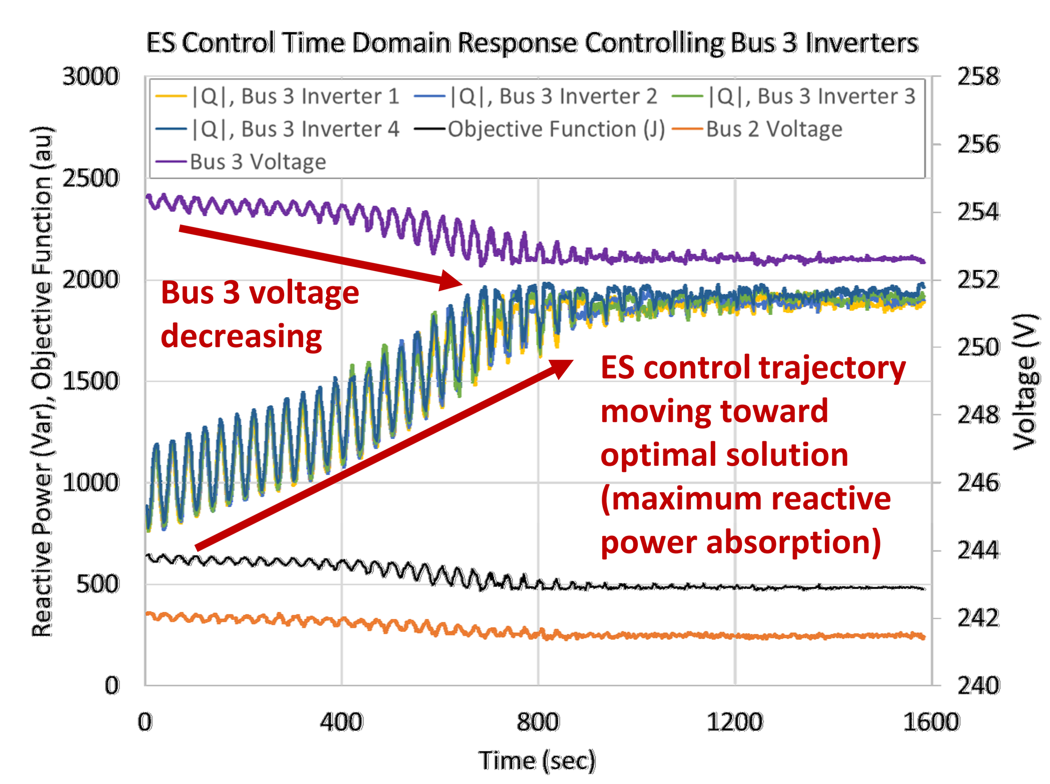


1. Fixed PF commands



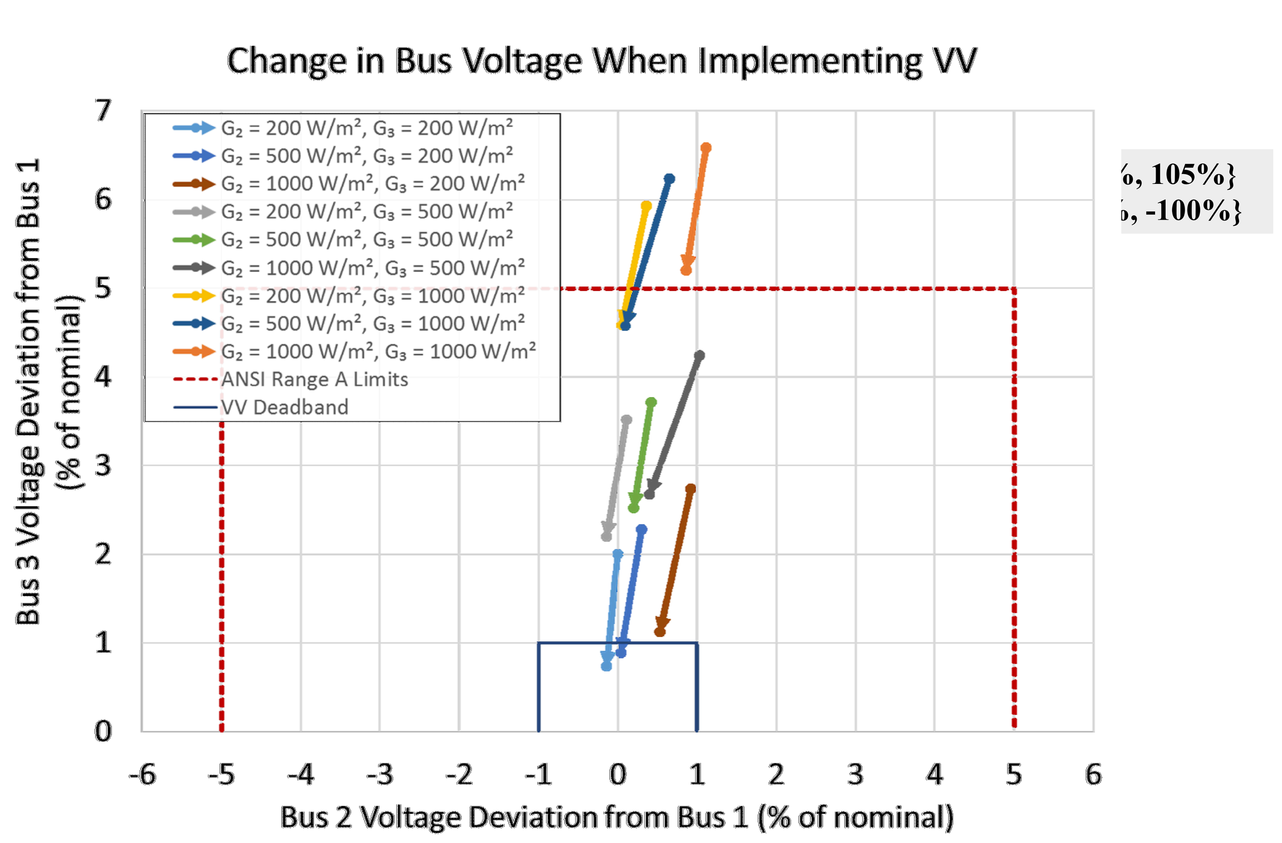
Bus voltages for different DER power factor setpoints.

2. ES Control



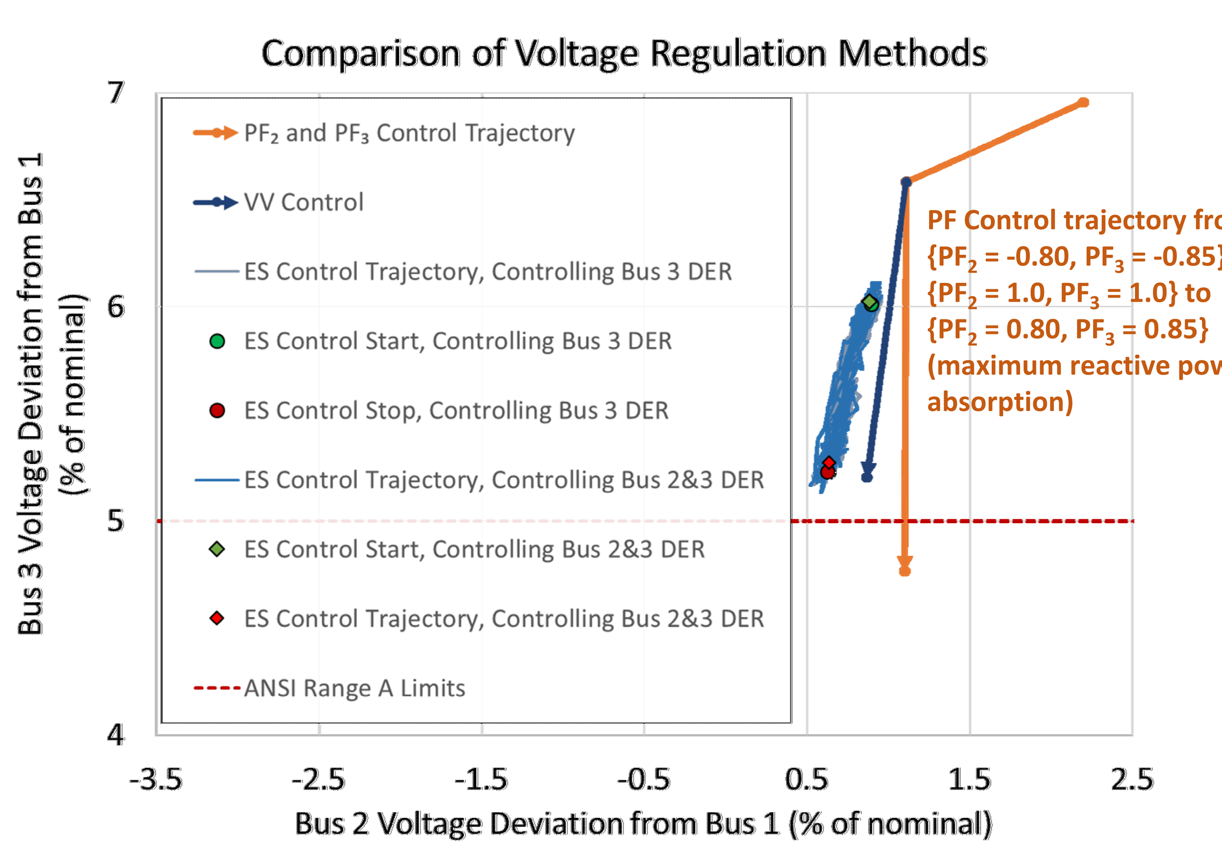
ES control results in the time domain.

3. Volt-Var Function



Bus voltage reduction when employing volt-var control.

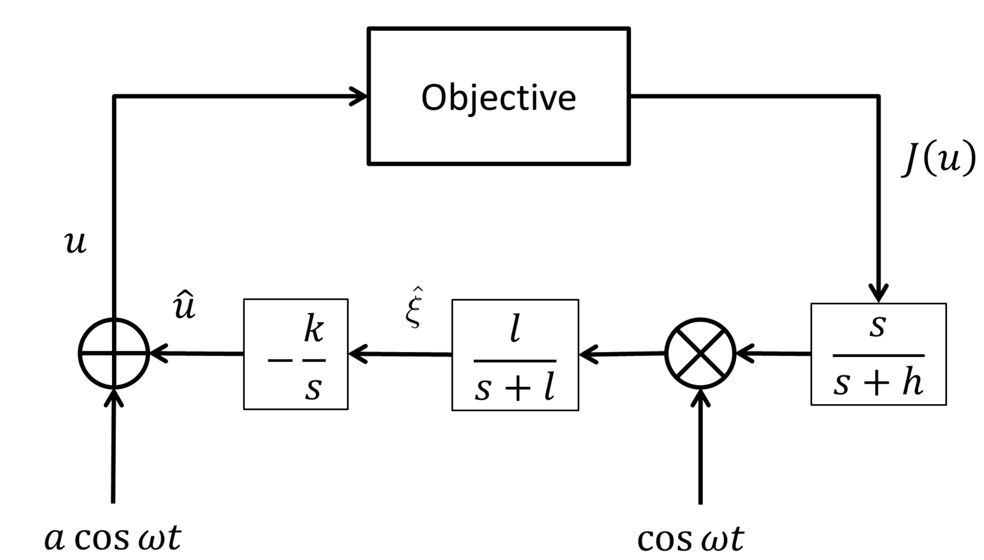
Results Summary



Results summary for all the voltage regulation controllers.

ES Control Theory

Extremum Seeking Control is a real-time optimization technique for multi-agent, nonlinear, and infinite-dimensional systems. The algorithm operates by adjusting system inputs in an effort to optimize measured outputs. The control uses sinusoidal perturbation inputs and demodulates system outputs to extract approximate gradients to perform the gradient descent.



ES control where parameters k, l, h, a, and ω are chosen by the designer. Details in [1].

Conclusions

Three voltage regulation techniques were employed on a test bed representing a rural feeder with nine PV inverters. All three methods were effective in reducing voltages on the distribution circuit.

- PF control relied on a centralized control algorithm to issue setpoints to each of the DER so it was computationally and communications intensive, but it produced the greatest voltage improvement.
- The volt-var function was convenient because it could be preprogrammed or updated infrequently. VV did not produce as significant a reduction in voltage as PF control on Bus 3, but it was highly effective and fast.
- ES control required high communication speed and proper selection of ES control gains, probing frequencies, and probing magnitudes—but the method showed promise to reach optimal voltage regulation DER setpoints. Additionally, other objectives (e.g., reduced substation active power) can be included in the objective function.

It is recommended that this technique be investigated in further detail with different physical systems to determine the feasibility of field deployment.

[1] D.B. Arnold, M. Negrete-Pincetic, M. D. Sankur, D. M. Auslander, D. S. Callaway, Model-Free Optimal Control of VAR Resources in Distribution Systems: An Extremum Seeking Approach, IEEE Trans. Power Systems, Vol. 31. No. 5, Sept. 2016.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. This material is based upon work supported by the U.S. Department of Energy Grid Modernization Laboratory Consortium (GMLC) Community Control of Distributed Resources for Wide Area Reserve Provision project.