DERConnect – A Distributed Energy Resources Testbed for Solar Power Integration

Jan Kleissl, Adil Khurram, Keaton Chia, Scott Brown, Aditya Mishra, Jorge Cortes, Raymond de Callafon, Rajesh Gupta, Sonia Martinez, David Victor

University of California, San Diego, La Jolla, CA 92093

***Abstract*—Distributed Energy Resources Connect (DERConnect) is a National Science Foundation user facility to facilitate testing of distributed communication and controls algorithms at scale. DERConnect caters to industry and academic users in the electric power sector. DERConnect will provide testing capabilities of 1,000s of real DERs and millions of simulated DERs. DERConnect is designed to test intelligence on the grid edge by configuring the DERs in any communication architecture such as peer-to-peer, hierarchical, and centralized. DERConnect also enables cybersecurity test, social science tests, and advanced building controls. DERConnect will open to the research community in 2025. This paper describes DERConnect use cases and instructs potential future users of when and how to engage.**

Keywords—distributed energy resources, distributed control, testbed, autonomous energy grids *(key words)*

I. Introduction

Distributed Energy Resources (DERs) are becoming ubiquitous on electric power grids. DERs can be generators, flexible loads, or both. DERs are generally deployed for economic or reliability reasons. The most prevalent combination of DERs is solar photovoltaic (PV) together with battery energy storage systems (BESS). Typical behind-the-meter DER deployments consist of a few DERs which are centrally controlled, e.g. by a microgrid controller, and to the outside act as one entity. The "local" arrangement is relatively trivial to control as ownership of the DER and communication infrastructure is centralized, most use cases occur over long time horizons, and the control algorithms and communication requirements are well-understood and manageable. For example, for demand charge management in commercial buildings, historical data of load and PV generation, as well as utility tariffs suffice for the controller to compute a BESS dispatch signal for the next 24 hours to shave the net load peak.

For transmission system services, however, DER coordination and aggregation becomes complex. The US electric grid increasingly requires real-time adaptation by advanced controls. Controllability of many DERs will enable a high level of renewable penetration while providing benefits to the system. To realize this potential, novel mechanisms are needed for the coordinated management of large numbers of heterogeneous types of loads and DERs with various behavioral characteristics. These mechanisms should ensure the guaranteed availability of negotiated quality of service as required by the system and constrained by the flexible limits of loads. Critical science challenges are, for example, (i) the design of joint communications infrastructures to assess the performance of distributed optimization methods in case of unreliable communications channels, communications outages, and cyber-attacks; and (ii) avoiding the synchronization of control actions of millions of devices to ensure stable system operations while dampening oscillations [1].

The future reliability and cost-effectiveness of the electric power grid hinges upon the ability to control fleets of DERs which may number in the millions. These fleets of DERs can satisfy classical functions such as shed, shift, shape, and shimmy [2]. A typical use case that motivates our testbed is frequency control, where new control set points are issued every few seconds. Such deployments are challenged by massive communication requirements and potentially unreliable devices and means of communications. It is envisioned that such future grids will be autonomous and controlled in a decentralized way. A workshop by the National Renewable Energy Laboratory (NREL) concluded that "[A] major limitation in developing these new technologies for autonomous energy systems is that there are no large-scale test cases that can be used to validate the feasibility of the algorithms necessary for combined energy systems. These test cases serve a critical role in the development, validation, and dissemination of new algorithms before they can be transferred into the operations of real systems. (…)" [1].

Based on earlier work in the ARPA-E NODES program[3], In 2020 the University of California, San Diego was awarded a National Science Foundation Mid-Scale Research Infrastructure (RI) grant to construct a testbed that is dedicated towards the control and optimization of millions of DERs. The testbed will open in 2025. Any US entity can apply to execute research projects at DERConnect for a modest user fee. The purpose of this paper is to introduce this testbed to the PVSC community and invite potential future collaborators to include testing in their mid-range RD&D schedule and in funding proposals.

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In this paper, Section 2 provides the objectives and an overview of DERConnect. Section 3 provides a sample use case. Section 4 includes a summary, the timeline of the DERConnect development, and an invitation for collaboration.

II. DERConnect Objectives

A. Objectives

The goal of the project is to build an experimental research instrument, DERConnect, that will be broadly accessible to the research community as a system-level testbed of methods, tools and datasets to evaluate novel distributed control algorithms (Figure 1). The research facility will enable testing of novel distributed control algorithms at scale for both mathematical and data-driven control approaches, as well as social-science research on the interaction between humans and energy consumption. DERConnect will enable near real-time control trials on up to 2,500 real and realistically operating DERs, hardware emulators that can be programmed to represent real DERs, HIL equipment linked with a communication system, and 2 million independent simulated DERs. DERConnect will establish for the first time a grid-connected and customizable power system with all the required components and DER types for large-scale distributed control in one place. Real-time remote access will provide users with unparalleled experience like in a control room.

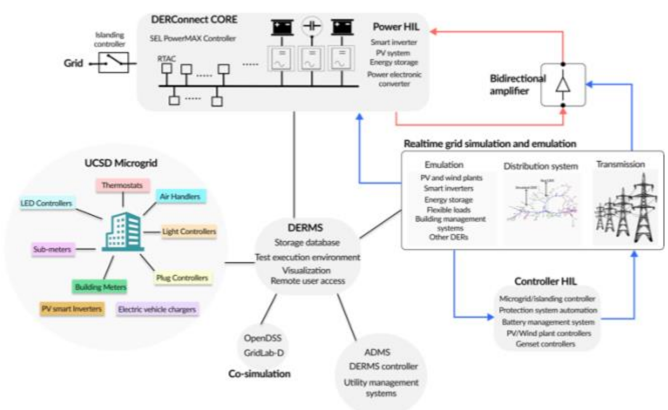

Fig. 1. DERConnect will feature an unprecedented diversity and number of Microgrid DERs (left circle) and ancillary simulation, metering, and controls equipment (top and right) to enable distributed controls testing at scale.

B. DERConnect Overview

DERConnect consists of two main components.

A DERConnect Core, which includes: (i) an islanding controller to electrically isolate the facility when needed; (ii) simulators and emulators to scale the number and diversity of DERs to up to 2 million.

DERs throughout the campus microgrid, which can be controlled separately for specific tests or in conjunction with the DERConnect Core. Each DER will have a physically separate, but dedicated associated control agent to emulate any controls topology and communications protocol. DERConnect controllable loads include Heating, Ventilation, and Air Conditioning (HVAC) systems, lighting, solar photovoltaic (PV), battery energy storage (BES), and electric vehicles (EVs).

C. Testing Hierarchy

We envision a three-tiered approach to carry out tests. The proposed infrastructure will be capable of performing both focused / individual tests (e.g., a specific occupancy estimation algorithm in a building) and integrating tests (e.g., an algorithm for the coordinated management of DERs that combines collective decision making, individual DER control, and grid sensing). The three testing phases for validated users are:

Software simulations: Any algorithm will first be evaluated using software-only simulations. This first step is essential to: (i) corroborate claims regarding stability, performance, safety, and optimality; (ii) assess scalability and complexity; and (iii) evaluate the behavior against realistic practical conditions regarding latency, DER dynamics, and disturbances before transitioning to hardware implementation and testing.

HIL testing will consist of the OpenDSS models interfaced with a high-fidelity HIL simulator, which will allow for simulation of a wide range of DER configurations and grid operating conditions. A limited number of actual physical DERs interfaced through a power amplifier.

Deployment at DERConnect: The culmination of the testing process will be the actual deployment of the proposed algorithms in the DERConnect infrastructure with 2,500 actual DERs, 10,000 hardware DERs, and 2 million simulated DERs.

III. Sample Use Cases

A. Sample Use Case: Real and Simulated DERs with distributed control for frequency regulation

Here we describe a sample use case. The algorithm presented in Figure 2 uses forecasted renewable energy availability to solve a chance constrained optimal power flow problem. The chance constraints ensure that, with high probability, there will be enough available renewable energy to operate at the chosen set points. The algorithm solves the problem in a decentralized fashion after reformulating into a deterministic optimization problem. The algorithm would be applied to the topology shown in Fig. 3. Additional test cases are described in[4].

B. Other Types of Experiments

Social science experiment examples are (i) how incentives around the timing of EV charging to align with excess solar power and effects of these incentives on slower Level II chargers when compared with DC fast chargers. In this way we can assess how individual decisions aggregate in the larger system-wide behavior—such as timing of system-wide peak power consumption. (ii) Using HVAC systems, reveal how collective choices about thermostat settings affect individual welfare. We will look, experimentally, at two aspects of collective choice. One is how different aggregation rules could affect adjustment of HVAC equipment—for example, different goals such as improving average or outlier perceptions of comfort. This work contributes directly to collective action research that examines how different aggregation rules and institutions affect collective outcomes. The other is how transparency of information affects behavior—for example, we will run experiments that examine the difference between outcomes when individual preferences are visible or anonymous to other members of the group and also when individuals have access to information about the cost of different HVAC settings.

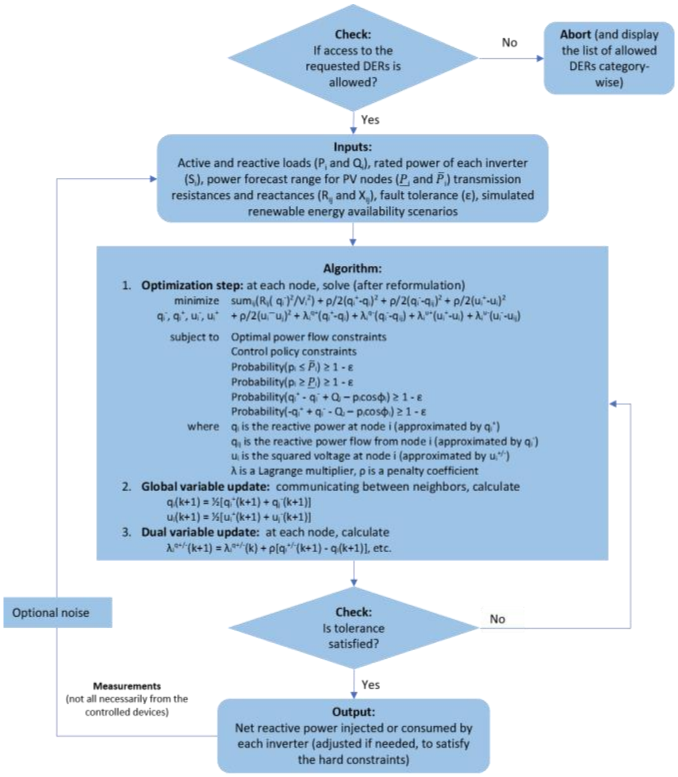

Fig. 2. Sample test case on chance-constrained alternating direction method of multipliers (ADMM) approach for decentralized control[5].

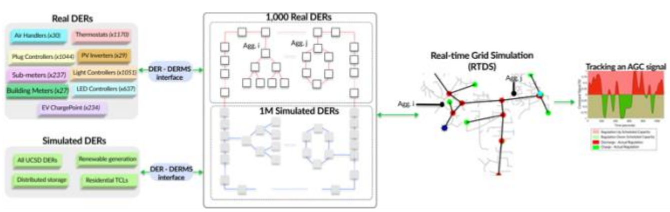

Fig. 3. DERConnect use case of distributed control for frequency regulation. Real (top left) and simulated (bottom left) DERs would be virtually arranged onto distribution and transmission grids and coupled with a Real-Time Simulator (RTS) to follow an AGC signal

Cybersecurity experiments: Any power grid facility must be designed to provide enhanced security from an increasing and evolving variety of threats. While the UCSD facility will be cybersecure, we will allow simulating newer types of cyber threats that we may have to mitigate in the future. The cybersecurity testbed will be developed to disrupt the functionality of the different components of the DERConnect framework. We will create a network model of the facility and annotate it with patterns of access at every node and information flow between nodes of the network. Each generated attack in the simulation mode will be first tested in isolation and then composite attacks will be generated by combining and interleaving them in different coordinated patterns. The building abstraction will be implemented in a graph database management system. A semi-automatic attack classification strategy will be developed from sample observations made at the nodes and edges. We will characterize the threat, determine the extent/nature of disruption caused by it, and develop a model about how single threats propagated or multiple threats acted conjunctively to lead to a larger disruption.

IV. Summary and Timeline

The DERConnect national test facility will enable the transition to an economical, autonomous, reliable, and dynamic power system. Just like on a supercomputer, users will be able to reserve time on DERConnect to run distributed controls and other experiments. DERConnect staff will be at your service to consult during the planning, facilitate the execution, and share data after the experiment. DERConnect building upgrades are currently under construction and we are conducting trials with several vendors to establish the communications and controls architecture with a target to release an RFP in summer 2022. DERConnect researchers will start running trials in 2023 and build documentation, intuitive user interfaces, and characterize the DERs. The microgrid DERs are expected to be available for trials to outside users in 2024. The DERConnect Core with real-time simulation and HIL capabilities is expected to open in late 2024 and the full testbed opening will occur in 2025.

We invite outside users to engage with us early on. Since DERConnect was designed to be self-sustaining, it will be funded through user fees. Academic partners should budget for such fees in grant proposals. User fees may be as low as $5,000 for simple on-off experiment and increase with the complexity and duration of the testing. Please consult with any of the authors to determine scope and cost for your experiments[6].

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