Automating Kentucky's Largest Battery

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Tour of the Battery

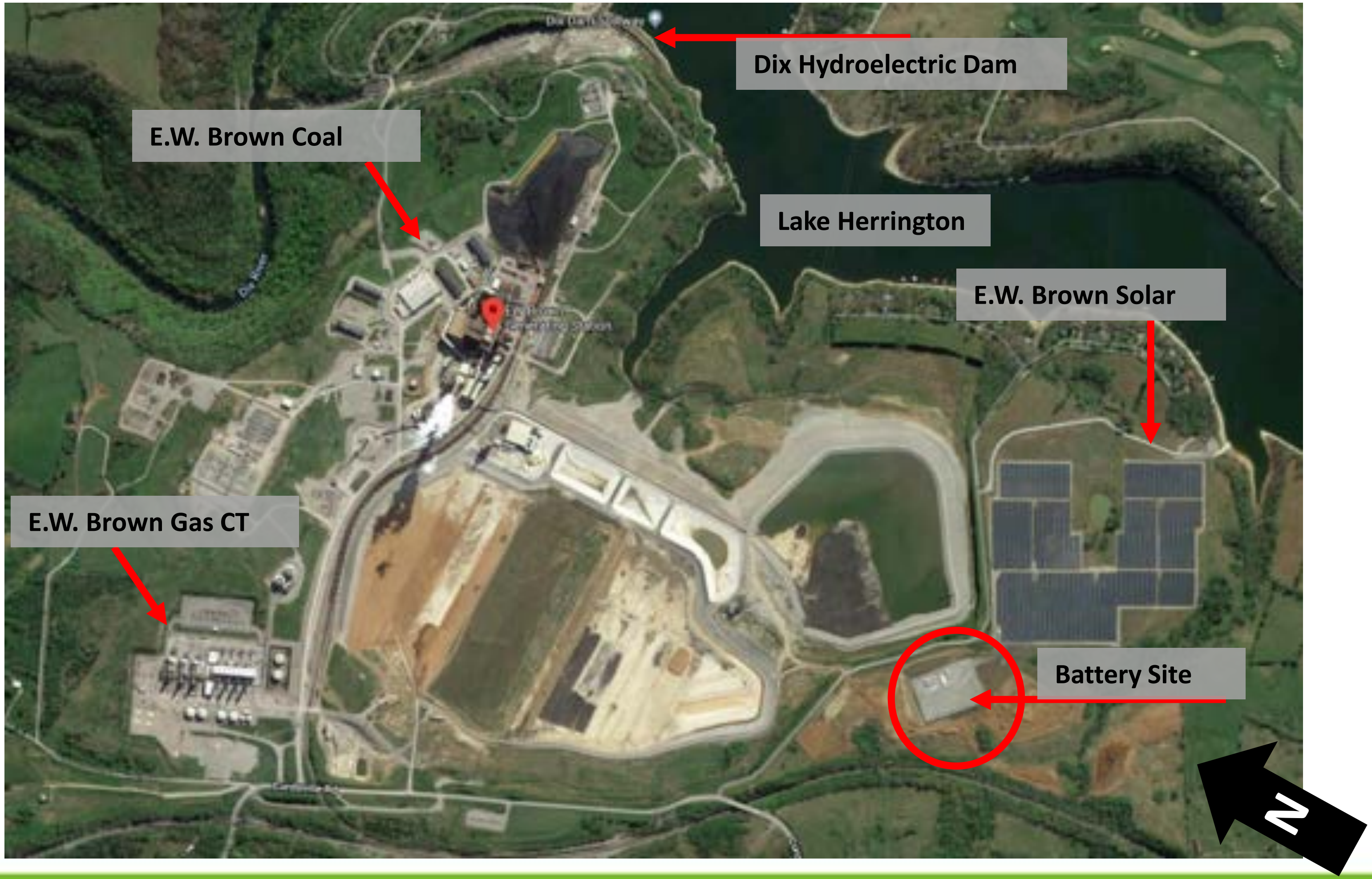
Battery Site Overview

Partnership with EPRI and the University of Kentucky.

LG&E and KU Energy operates Kentucky's first and largest utility-scale energy storage system—a 1-megawatt, 2-megawatt-hour lithium-ion battery. The battery is co-located with E.W. Brown Solar, allowing the company to explore how batteries can improve the inherent intermittency of solar power.

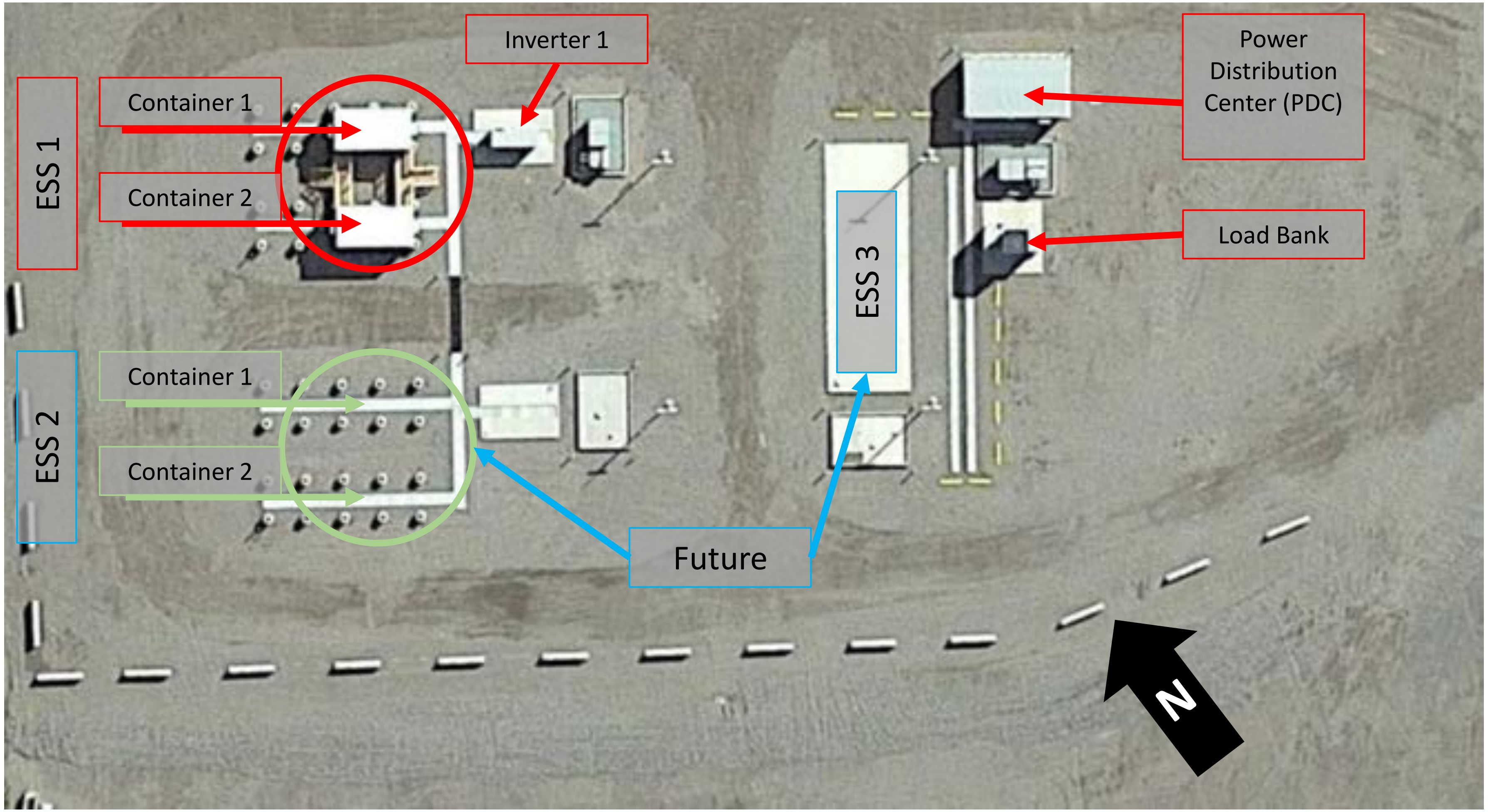
Map of E. W. Brown

E. W. Brown contains many different energy systems.



Location of Battery Containers

There are three separate skids for battery systems.



Increasing Site Storage

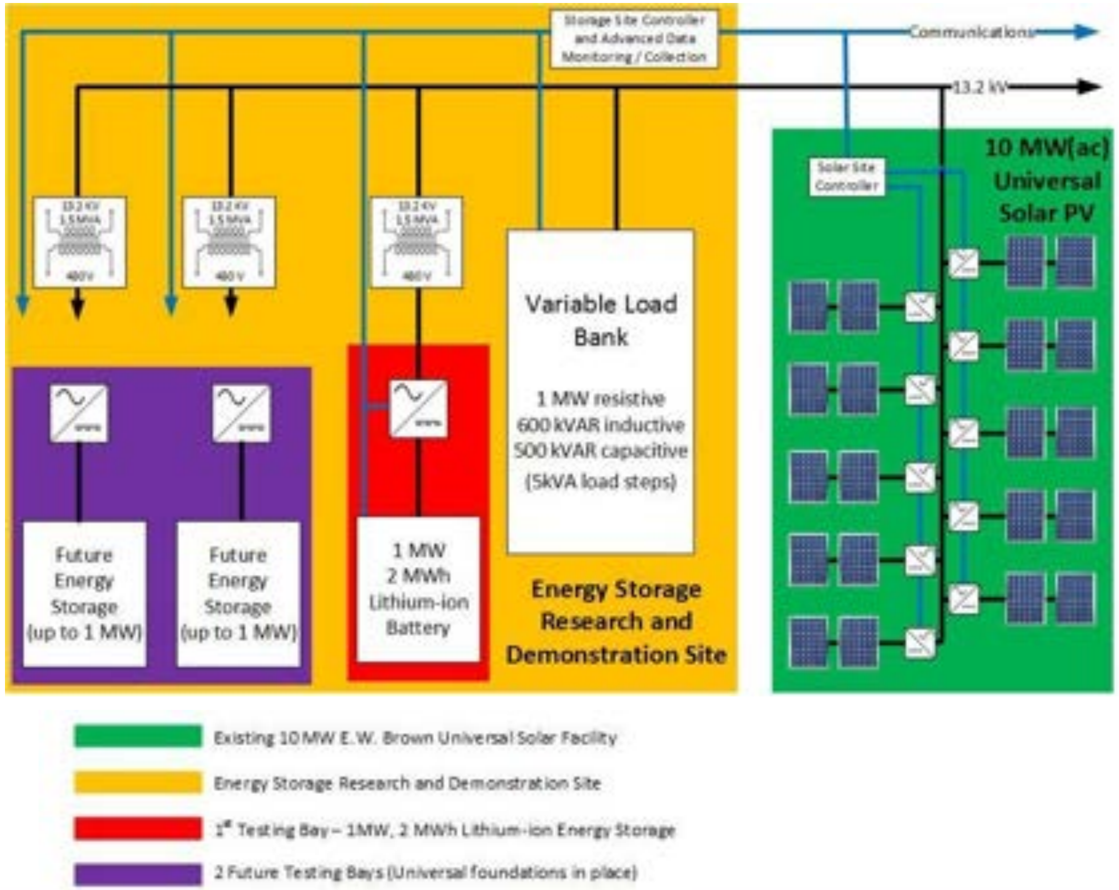
Planning for multiple projects to expand the site.

- A lithium-ion battery is planned for energy skid two.
- A vanadium redox flow battery is planned to be built on energy skid three.
- Currently planning for up to 500 MW lithium-ion storage site adjacent.

Site Features

The energy storage site has a modular construction.

- Three testing bays
- 1.2 MVA resistive, inductive, capacitive (RLC) load bank
- Grid-connected or islanded
- High accuracy metering and data logging
- User-facility-style site
- Operational: Dec. 2016



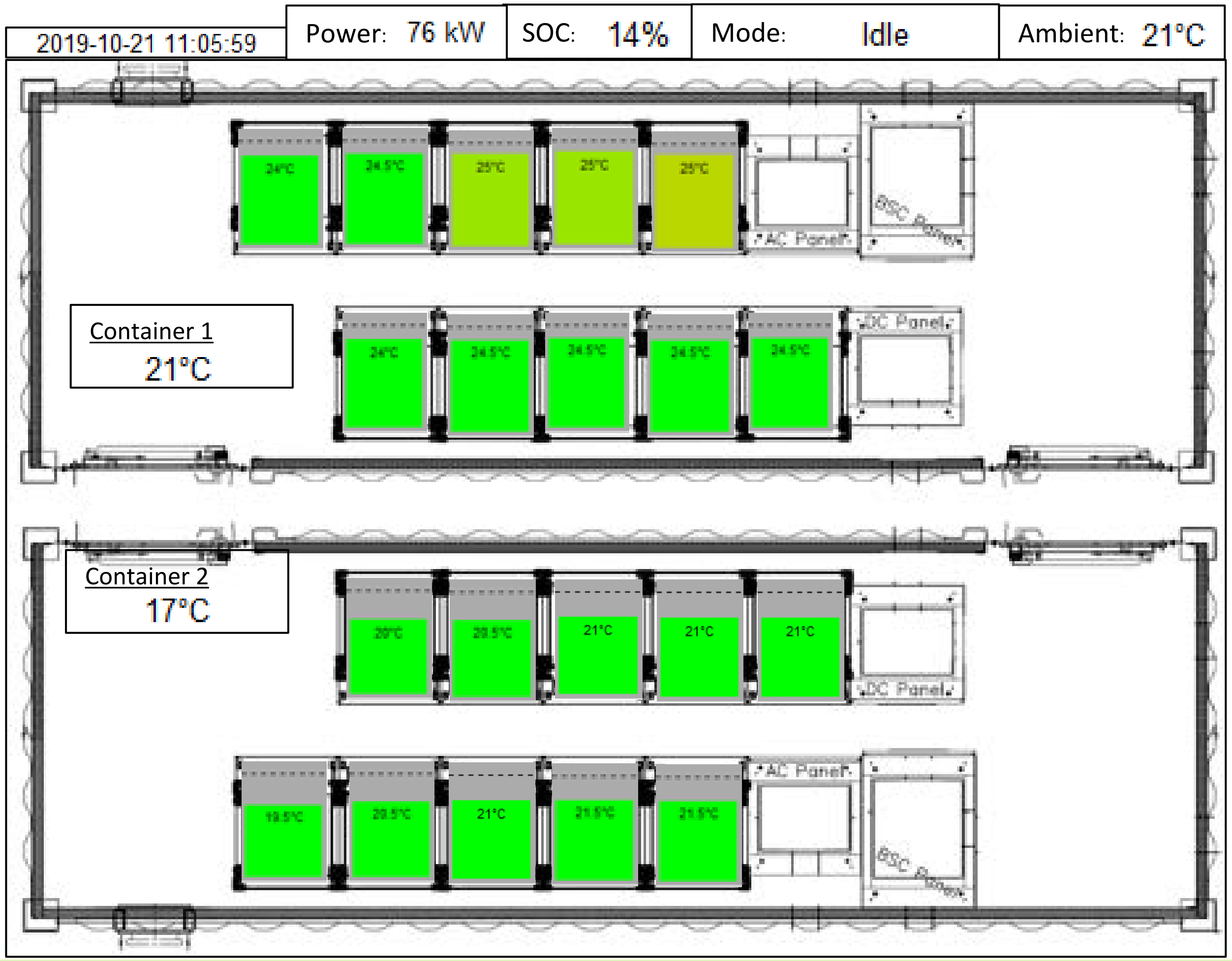
Inside the Battery

Open Rack of Battery Modules inside Container 1

4,760 Cells
14 Cells per Module
17 Modules per Rack
10 Racks per Container
2 Containers

Battery Closely Monitored

Modules heat up as the battery SOC rapidly changes.



100% Automation in Python

The battery is managed and operated by Python.

- Python was used to automate the battery energy storage system.
- Python scripts are exporting JSON files, which contain the specific battery operations.
- The script provides rudimentary artificial intelligence.

Automation Runs 24/7

The automation supports load and solar generation.

- Automation fulfils tasks that would normally require manual inputs, such as daily charges and nightly discharges.
- The code enforces set battery limits for state of charge and temperature.
- The battery can run based on sunrise and sunset times, allowing it to pair well with solar farm generation.
- Battery health is accounted for by enforcing rest, which ensures cell voltage balancing.

```
def start_target_soc(
        real_power: float,
        soc: float,
        start_time: Optional[int] = None,
        stop_time: Optional[int] = None):

    op_config = [
        ["realPower", real_power],
        ["targetSoc", soc],
        ["PPreferredOverQ", False],
        ["opIntervalMs", 1000]
    ]

    op_data = {
        "metaId": "DefaultTargetSocEssUnitOp",
        "configuration": op_config
    }

    if start_time is not None:
        op_data["scheduledStartTime"] = start_time

    if stop_time is not None:
        op_data["scheduledEndTime"] = stop_time

    response = requests.post(
        url=f"{GEMS_URL}/v1/operations/EssUnit1",
        json=op_data,
        headers=headers,
        verify=False
    )
    response.raise_for_status()
    return response

def remove_operation(op_id: str):
        response = requests.post(
            url=f"{GEMS_URL}/v1/operations/remove/"+op_id,
            headers=headers,
            verify=False
        )
        response.raise_for_status()

def Sunlight():
        # Call the login route.
        auth_key = login()

        # See if there are active or schedule tasks
        if len(Tasks_ESS_unit1) > 0:
            # Remove any scheduled operations
            for j in range(0, len(Task_IDs)):
                # If the task is scheduled, then remove it
                if Task_IDs.Status[j] == 'Scheduled':
                    Remove_all_op_id = remove_operation(Task_IDs.at[j, 'id'])

        # Create tasks for each item in the schedule df.
        for j in range(0, len(Schedule)):
            task_op_id = start_target_soc(
                real_power=float(Schedule.Rate[j]*1000),
                soc=float(Schedule.SOC_Target[j]),
```

Automation Challenges

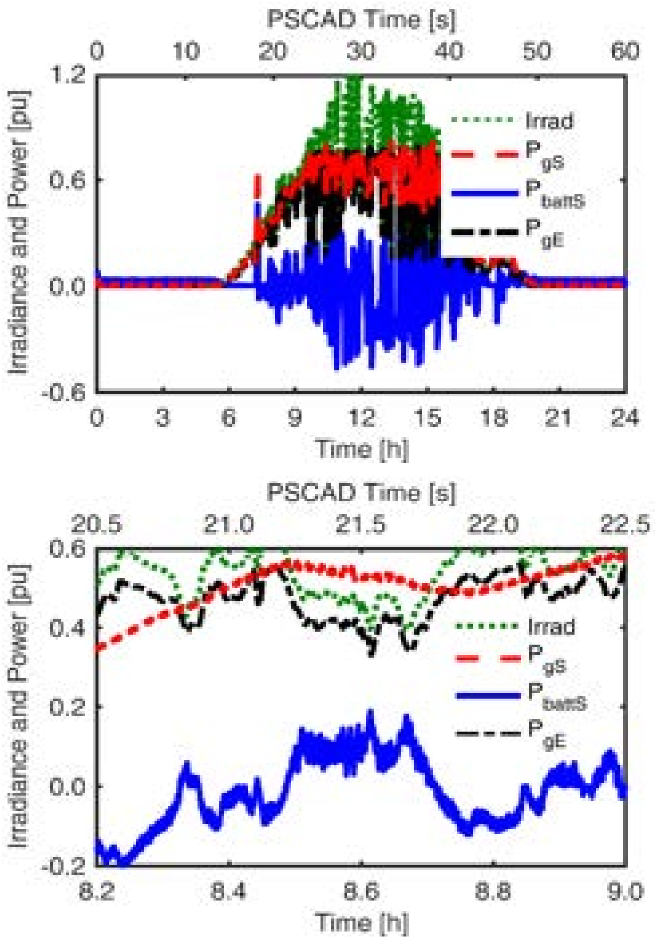
The battery’s computer has multiple levels of security.

- The most difficult part of automation was getting through multiple network firewalls, along with the battery's security key.
- Security was overcome by putting the automation inside the firewalls.
- Other challenges included:
  - The battery’s airgap from internet connection
  - Math for scheduled charging and discharging
  - Allocating time for cell voltage balancing
  - Understanding the procedure for automation

Battery Storage Application

Solar Power Smoothing

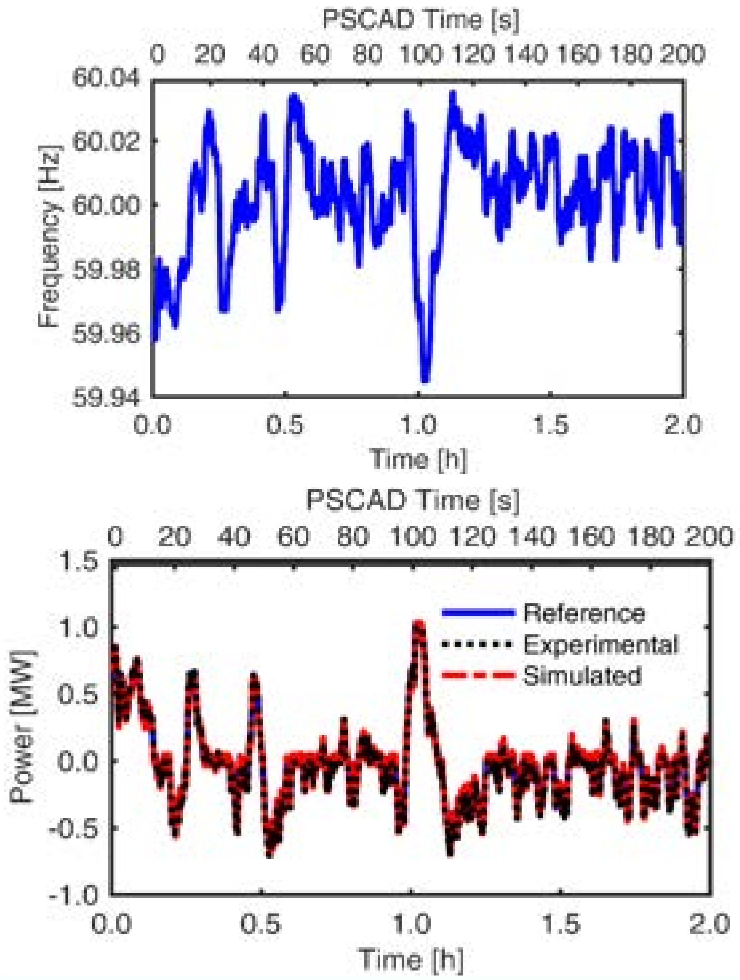
- BESS may be used to smooth the solar output power variation in order to:
  - Improve the delivered power quality.
  - Meet grid ramp rate limitations.
  - Limit potential frequency deviations.
- The BESS is controlled to supply the power difference between the available solar power and its computed moving average.



Battery Storage Application

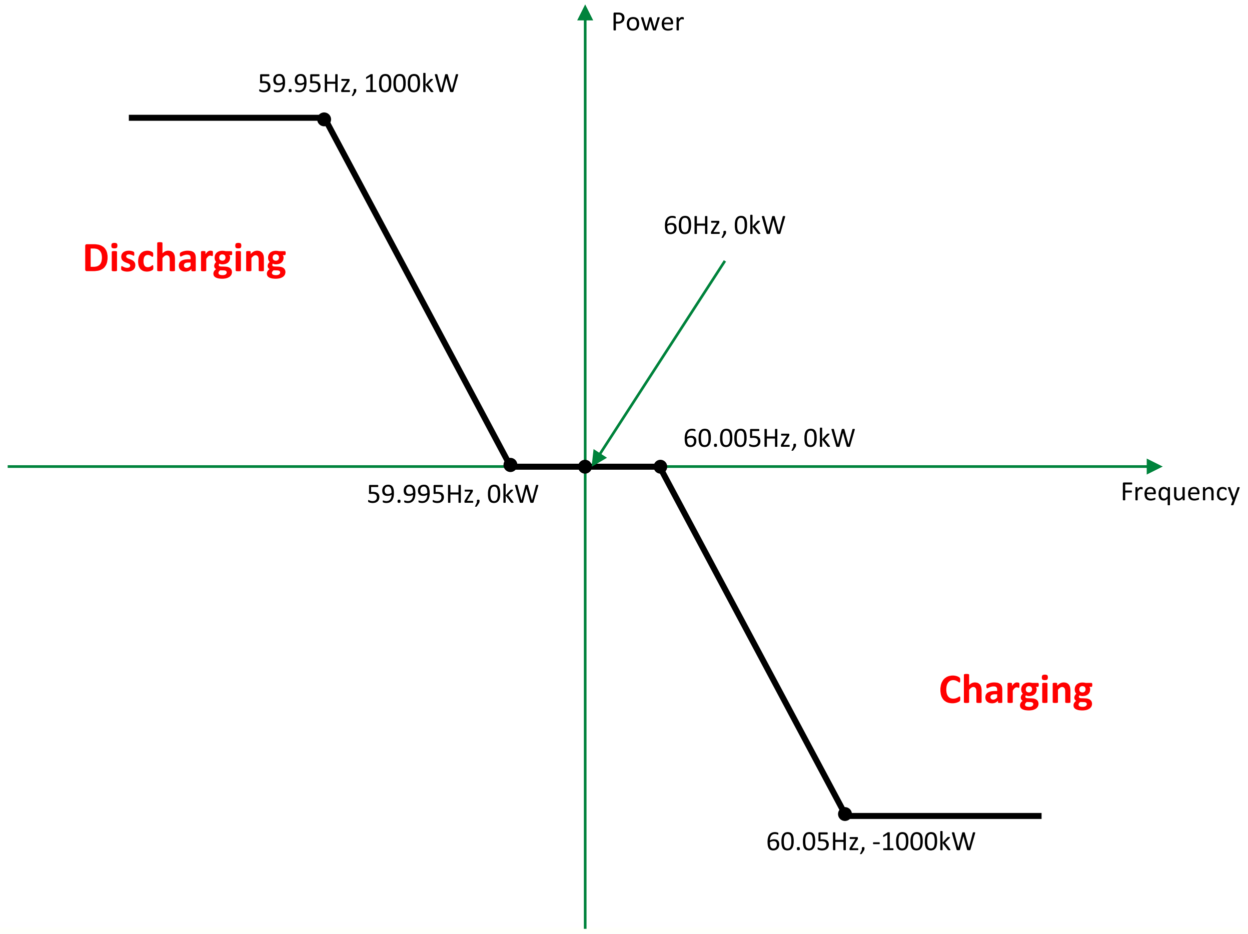
Frequency Regulation

- The grid frequency tends to increase when the generation is in surplus and falls when the load exceeds the generation.
- BESS with extremely high ramping capabilities may be explored for frequency regulation by charging/discharging based on frequency deviations.
- The developed BESS model and its response to frequency variation was analyzed through a PSCAD simulation study.



Frequency Regulation

The grid’s frequency could be adjusted using batteries.



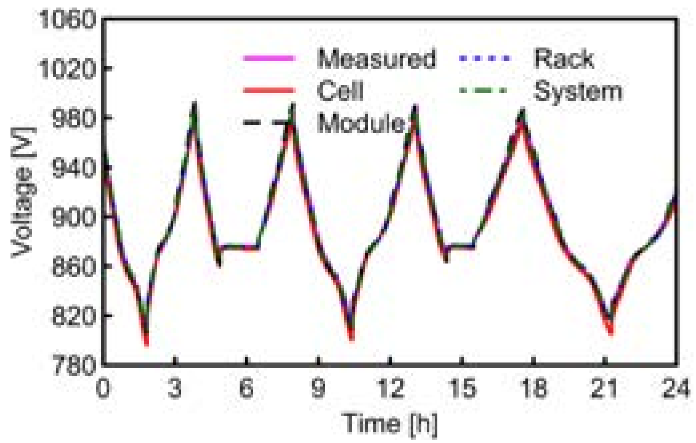
Battery Research

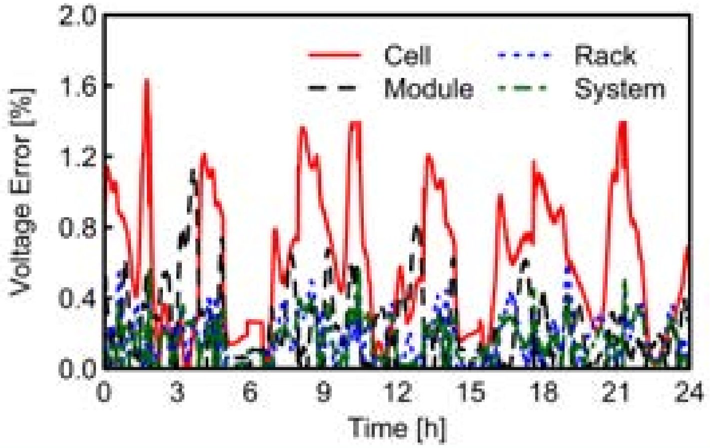
Battery Parameter Identification

Modeling utility-scale energy storage systems.

- The study proposed a new charge/discharge cycle for identifying the equivalent circuit parameters for utility-scale battery systems using equipment readily available at installation sites without the need for laboratory setups.
- This type of modeling is used to demonstrate that the equivalent circuit model for a reference cell, module, or rack of a BESS can be scaled to represent the entire battery system provided that the battery management system (BMS) is active and functional.
- Read the study:

Parameter Identification for Cells, Modules, Racks, and Battery for Utility-Scale Energy Storage Systems
O.M. Akeyo, V. Rallabandi, N. Jewell, A. Patrick, D.M. Ionel - IEEE Access 8, 215817-215826



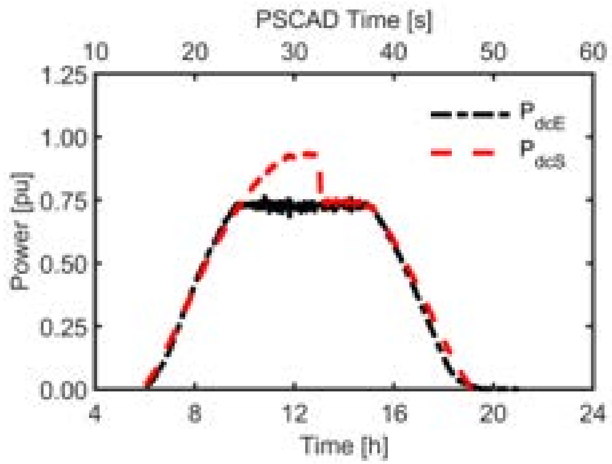


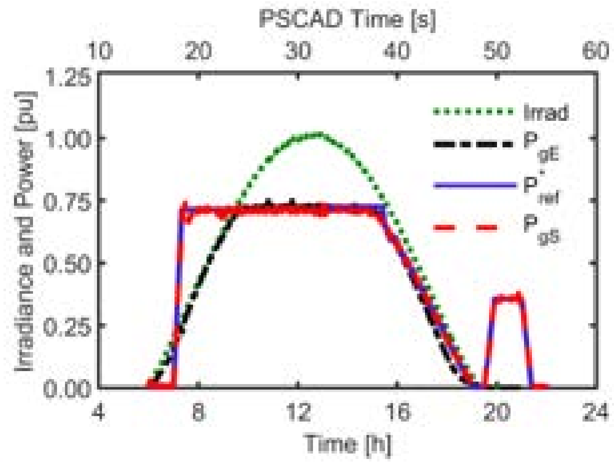
Direct Solar to Battery Connection

DC-DC connections may increase overall efficiency.

- The paper discusses a way to simply incorporate a battery into an existing solar PV system to store power that would otherwise be curtailed.
- The proposed configuration utilizes a single DC-DC converter capable of simultaneously operating as a charge controller and a maximum power point tracking device.
- With this configuration, the excess power that would otherwise be curtailed due to inverter rating limitations is stored in the battery and supplied to the grid during periods of reduced irradiance.
- Read the study:

The Design and Analysis of Large Solar PV Farm Configurations With DC-Connected Battery Systems
O.M. Akeyo, V. Rallabandi, N. Jewell, D.M. Ionel - IEEE Transactions on Industry Applications 56 (3), 2903-2912





Integrating Battery with Solar

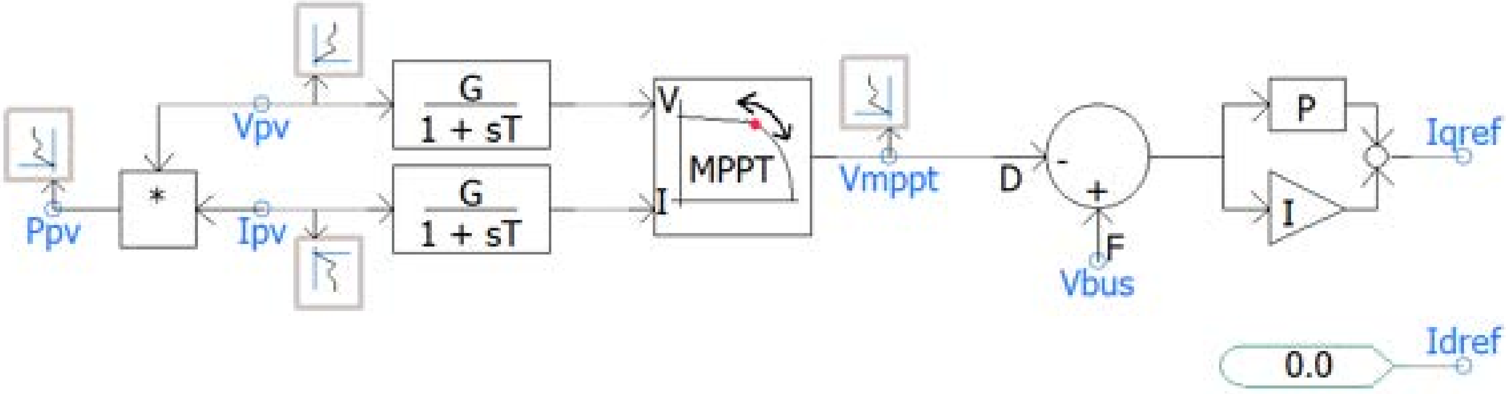
Models assist in plans to add more battery and solar.

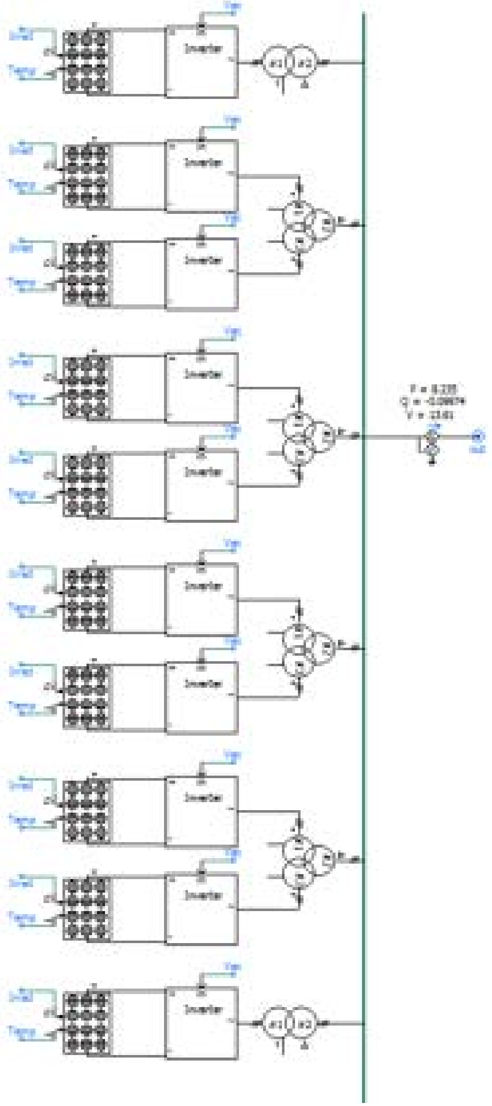
- The paper analyzes the configuration, design and operation of multi-MW grid connected solar PV systems with practical test cases provided by a 10MW field development.
- The proposed configuration also incorporates a utility scale battery energy storage system (BESS) connected to the grid through an independent inverter and benefits of the experience gained with a 1MW 2MWh BESS large demonstrator.
- Read the study:

Incorporating battery energy storage systems into multi-MW grid connected PV systems
O.M. Akeyo, V. Rallabandi, N. Jewell, D.M. Ionel - IEEE Transactions on Industry Applications 55 (1), 638-647

PSCAD Model for the PV System

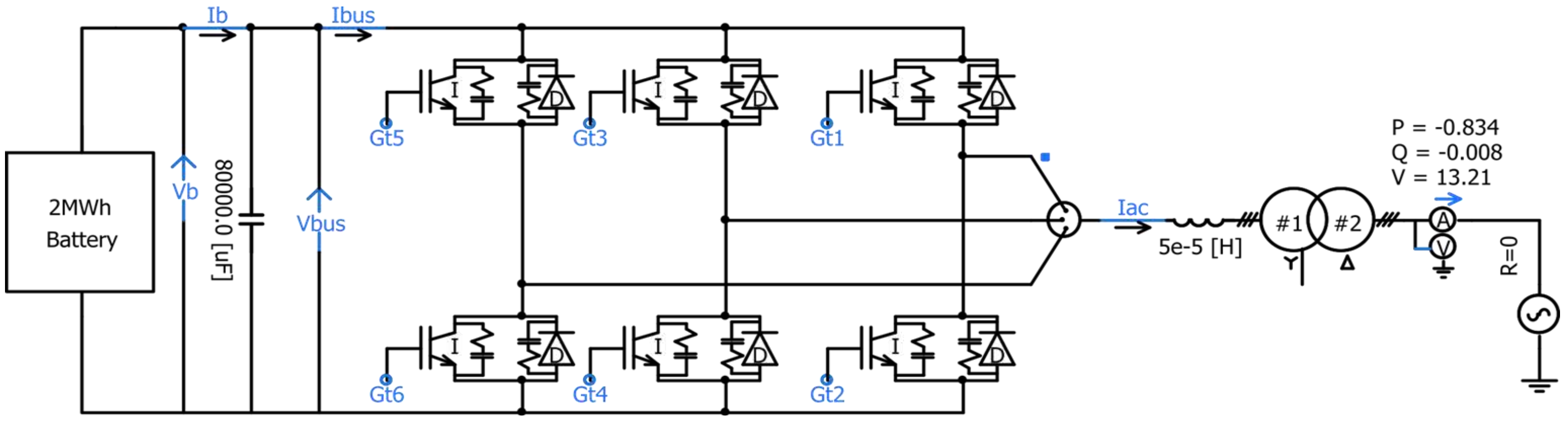
- 10MW PV array with series and parallel strings.
- Two 2-winding transformers (Y-Δ) and four 3-winding transformers (YY-Δ); all transformers are ungrounded.

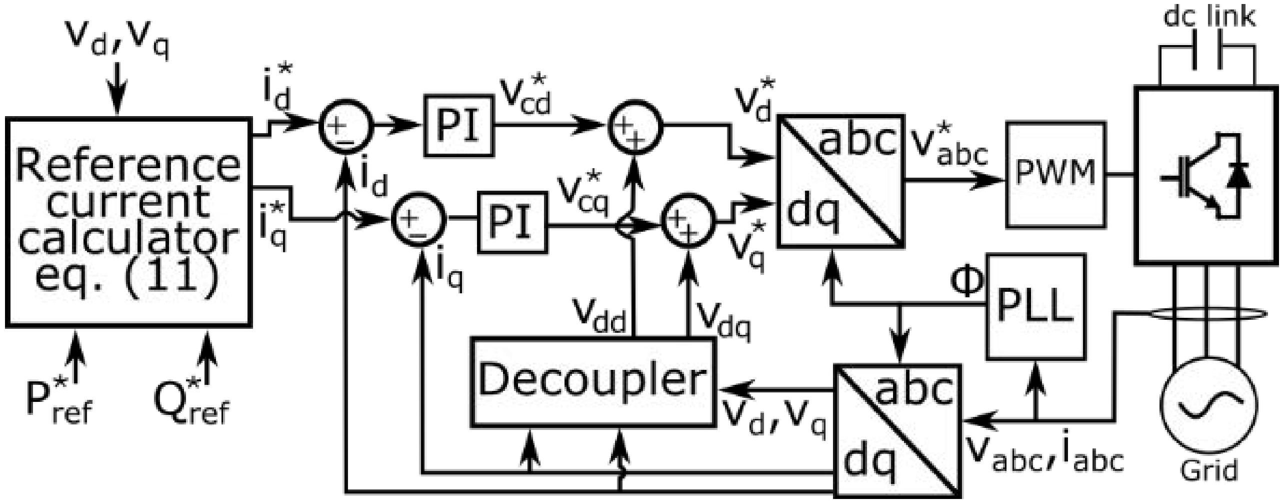




PSCAD Model for BESS

- A two-level three-phase DC-AC converter, which is capable of operation in the charging and discharging modes is employed for the grid interconnection of the battery bank.
- A decoupled scheme allowing the independent control of real and reactive powers is employed.





Battery Publications

8 Published Academic Research Papers

- Parameter Identification for Cells, Modules, Racks, and Battery for Utility-Scale Energy Storage Systems
  O.M. Akeyo, V. Rallabandi, N. Jewell, A. Patrick, D.M. Ionel - IEEE Access 8, 215817-215826

- The Design and Analysis of Large Solar PV Farm Configurations With DC-Connected Battery Systems
  O.M. Akeyo, V. Rallabandi, N. Jewell, D.M. Ionel - IEEE Transactions on Industry Applications 56 (3), 2903-2912

- On the Control of a Solid State Transformer for Multi-MW Utility-Scale PV-Battery Systems
  O.M. Akeyo, Y. Zhang, J. He, D.M. Ionel - 2019 IEEE Energy Conversion Congress and Exposition (ECCE), 6481-6486

- Measurement and estimation of the equivalent circuit parameters for multi-MW battery systems
  O.M. Akeyo, V. Rallabandi, N. Jewell, D.M. Ionel - 2019 IEEE Energy Conversion Congress and Exposition (ECCE), 2499-2504

- Modeling and simulation of a utility-scale battery energy storage system
  O.M. Akeyo, V. Rallabandi, N. Jewell, D.M. Ionel - 2019 IEEE Power & Energy Society General Meeting (PESGM), 1-5

- Incorporating battery energy storage systems into multi-MW grid connected PV systems
  O.M. Akeyo, V. Rallabandi, N. Jewell, D.M. Ionel - IEEE Transactions on Industry Applications 55 (1), 638-647

- Power Utility Tests for Multi-MW High Energy Batteries
  O.M. Akeyo, H. Gong, V. Rallabandi, N. Jewell, D.M. Ionel - 2018 7th International Conference on Renewable Energy Research and Applications, 1396-1399

- Improving the capacity factor and stability of multi-MW grid connected PV systems with results from a 1MW/2MWh battery demonstrator
  O.M. Akeyo, V. Rallabandi, N. Jewell, D.M. Ionel - 2018 IEEE Energy Conversion Congress and Exposition (ECCE), 2504-2509

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- Power and Energy Institute of Kentucky (PEIK)
- SPARK Laboratory

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