Modular, Secure, and Replicable Microgrid Control System for Generation and Storage Management at Military Installations

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Project Team

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- Overall microgrid design
- Controller adaptation
- Technology transfer

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- System integration support

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- Sky-imaging technology

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- System integration
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- Seamless transition design
- Provision of smart inverters

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Problem Statement

- Existing microgrids are diesel-intensive, since renewable-intensive microgrids are difficult to implement and control for long-duration islanded operation
- Result: poor energy security and significant fuel use
- Present approach:
  - Inadequate control → interruption/instability and/or short islanded time
  - Customized deployments → costly and non-replicable
  - Diesel-intensive → energy security limited by fuel access, high emissions

Diagram:

- Diesel
- Diesel
- Diesel
- PV
- Battery
- Utility Grid
- Load
Technical Objectives

- Implement a design approach and control architecture that simplifies implementation and enables long-duration operation of islanded renewable-intensive microgrids
- Result: boosted energy security & reduced fuel use
- LBNL-team approach:
  - Multi-layer control → stable, islanded operation for 120+ hours with >1 MW of continuous load and 2 MW of peak for 4 hours
  - Renewable-intensive → 100+% renewable
  - Standardized deployments → cost effective and replicable
- The license for the supervisory control system will be free of charge
FHL Campus Overview

Connection and loading:

- 12 kV feed from PG&E
- Average load 2.4 MW, peak 4-6 MW
- 12 kV ring-type network with radial feeds to transformers & buildings

Assets:

- 3 MW grid connected PV
- 1.25 MW/1 MWh grid-connected battery storage
- 300 kW waste heat generation (commission in 2016)
- Diesel sets at building level for critical loads
Proposed Technology Description

Multi-Layered Control in Accordance with IEEE Std. 2030.7

- Layer 4: Demand management and grid interaction
- Layer 3: Short/Long-term energy planning and operation
- Layer 1 & 2: Real-time controls, industry standard devices
Scope of Microgrid backbone project:
• Layers 1 and 2
• PV and battery hardware
• SCADA system

Layers 1 & 2 will be able to operate resiliency functions without layers 3 & 4

Layers 3 & 4 provide optimized scheduling to support enhanced functions such as providing grid services

Scope of ESTCP project:
• Layer 3 and 4
•Super-capacitor
•OCC smart inverter
•PV micro-forecasting

Layers 3 and 4:
- Supervisory Controller / Energy Manager
- Grid interaction

Layers 1 & 2:
- Supervisory Controller / Energy Manager
- Grid interaction
Technology Description
Renewable Intensive (On/Off Grid)

- Multiple control objectives as costs or utility support
- Day and week ahead planning
- Real-time energy balancing
- Transition between on/off grid modes

![Graph showing PV, Load, Batt SOC, Batt Inverter, and Grid (kw) over time]
FHL 12 kV MAIN RING: Simplified One-Line

Typical Main Switch

SW 102 12 kV

From SW 1

Central PV (602 kW)

Bldg Load (1 kW)
Bldg Load (11 kW)
Bldg PV (22 kW)
1xBldg PV (61 kW)
Bldg Load (57 kW)
2xBldg Loads (30 kW)

Jn. Box

JC 270 12 kV

25 kVA 50 kVA

Bldg Load (1 kW) Bldg Load (10 kW)

Bldg Load (0 kW) Bldg Load (10 kW)

Bldg Load (20 kW)

2xBldg Loads (20 kW)
2xBldg Loads (20 kW)
2xBldg Loads (20 kW)

225 kVA 225 kVA 225 kVA

Bldg Load (35 kW) Bldg Load (50 kW) Bldg Load (0 kW)

45 kVA 45 kVA 45 kVA

Bldg Load (10 kW) Bldg Load (10 kW) Bldg Load (10 kW)

75 kVA 75 kVA 75 kVA

Bldg Load (40 kW) Bldg Load (10 kW) Bldg Load (10 kW)

Dotted lines represent future connections.

All Solar PV to be installed in Future.
Microgrid Switching - MV vs LV

Typical Main Switch

From PG&E

12 kV

MV-CB

Point Of Control

Jn. Box 12 kV

Service Xfmr 12 kV/208V

Building Load

From PG&E

Typical Main Switch 12 kV

MV-CB

Point Of Control

Building Load

Building PV

12 kV

JC

Service Xfmr 12 kV/208V

LV-CB

LV-CB
Group Level Switching at 12kV (MV) and its Impact

Approach:
- Circuit breakers are available only at 12kV main ring.
- Each circuit breaker controls a group of transformers/buildings.
- Control is at the group level. No individual control at building level.

Consequences:
- Switching OFF a 12kV circuit breaker for load shedding disconnects both building loads and connected PV. This results in loss of generation.
- Partial load shedding within a group is not possible.
- This design permanently assigns buildings as critical and non-critical. It is not possible to reassign them later.
- 12kV switching could cause high transformer inrush currents. This becomes critical during black start. Mitigating equipment may be required if storage inverters are not able to handle this high inrush current.
**Assumptions:**
- Circuit breakers (H-CB) are available only at 12 kV buses. Control is at the 12 KV bus level.
- No low-voltage (208V and 480V) breakers are available.

**Initial conditions:**
- FHL experiences a complete power outage. FHL network separates from PG&E
- All 12 kV buses have no service.
- All PV and ES are out of service but ready.

**Black-start approach:**
- Open all H-CBs. All service xfmrs + loads downstream from H-CBs are disconnected.
- Energize 12 kV buses using the available energy storage (ES). This is a no-load energizing (only buses are energized). Then close all H-CBs in succession, one at a time.
- When an H-CB is energized, a high inrush current from the transformer is expected. It may cause the 12-kV bus voltage to collapse if the ES cannot ride through the inrush current.
- Microgrid may not form. Additional equipment and/or switching approaches are needed to mitigate inrush currents and provide flexibility in load assignment.
Inrush Current with MV switching –
During islanded operation the highest inrush current occurs during the switching of 1500 kVA transformer

SW 200
ORTC MAIN SWITCH
SW 0
12 kV

Sectionalizer

750 kVA
1000 kVA
1500 kVA
1500 kVA
750 kVA
500 kVA

Bldg Load
Bldg PV
Bldg Load
Bldg PV
Bldg Load
Bldg PV
Bldg Load
Bldg PV
Bldg Load
Bldg PV
Bldg Load
Bldg PV

All Solar PV to be installed in Future.
Microgrid Switching at LV and its Benefits

**Approach:**
- Control is shifted to the Low Voltage side.
- This enables independent control of building loads and generation.

**Benefits:**
- Separate control of building load and generation allows load shedding without loss generation.
- Partial load shedding within a group is possible.
- Ability to reassign buildings as critical / non-critical as and when needed.
- Since switching is done on the low voltage side, black start is possible without inrush current risk.
- Transformer consolidation significantly reduces the number of transformers and control points (refer to next slide).

**Diagram Details:**
- From SW 1
- SW 102 → 12 kV
- LV-CB Point Of Control
- Central PV
- Bldg Load (NC), Bldg PV, 2xBldg Loads (2xNC), 2xBldg Loads (2xNC), 5xBldg Loads (5xNC)

C → Critical Load
NC → Non-Critical Load
Black Start: LV Switching

Assumptions:
- Circuit breakers (H-CB) are available at 12 kV buses.
- Low-voltage breakers (L-CB) at 208V and 480 V are available.

Initial conditions:
- FHL experiences a complete power outage. FHL separates from PG&E.
- All 12 kV buses have no service.
- All PV and ES are out of service but ready.

Black-start approach:
- Let all H-CB breakers remain close.
- Disconnect all loads by opening respective 208/480V breakers/switches (L-CB)
- Energize all 12 kV buses using energy storage. Employ soft-switching strategy to slowly ramp the bus voltage to nominal. Inrush current from the service transformer may be lower and can be accommodated by the energy storage.
- Connect loads and generation one by one from low voltage side.
- Microgrid may form successfully.
Transformer Consolidations

From SW 1

Typical Main Switch

SW 102 12 kV

Central PV (602 kW)

Bldg Load (NC)
Bldg Load (11 kW) (C)
Bldg Load (10 kW) (NC)

2xBldg Loads (20 kW) (2-NC)
2xBldg Loads (20 kW) (2-NC)
Bldg Load PV (35 kW)

Bldg Load PV (61 kW) (2xC)
Bldg Load PV (57 kW) (C)
Bldg Load (30 kW) (2xNC)

Optimizing the LV Infrastructures which will result in lower LV Switches
Transformer Consolidation to Enable More Optimized Infrastructure LV switching

From SW 1

Typical Main Switch

SW 102 → 12 kV

Jn. Box

Schematic diagram showing distribution of loads and transformers, with notes on critical and non-critical loads:

- Central PV (602kW)
- CLUSTER A2-1
- CLUSTER A4-1
- CLUSTER A4-2
- CLUSTER A4-3
- CLUSTER A4-4

Legend:
- C → Critical Load
- NC → Non-Critical Load

KVA ratings and load descriptions for various building loads are shown on the diagram.
Control on Low-voltage side provides flexibility to disconnect building loads without disconnecting PV

Cluster # A2-1

C → Critical Load
NC → Non-Critical Load

An Illustration of Potential LV Switching Implementation through Infrastructure Consolidation
Transformer inrush current and its impact

- Inrush current during the energizing could be much higher than the full rated current. It is short lived – a few cycles only.
- Inrush currents can be as high as 6 and 18 times the rated current. Magnitude of inrush current depends on several factors – e.g.
  - Primary voltage
  - Transformer saturation curve
  - Short circuit capacity of the network – lower the short circuit level, lower the inrush current

- Impact
  - Inrush currents are reactive and can cause voltage drops
  - Inrush currents do not normally pose any challenge in grid connected mode as rotary generators are designed to handle these high currents
  - However inverters are not designed to carry these. Typically they can handle up to 2 to 3 times their rated current but not more.
FHL has three interconnection options:

a) SB-83 for the United States Armed Forces, from PG&E: Maximum onsite generation is 1 MW above the minimum load up to 14 MW → The 1.5 MW minimum load at FHL enforces a 2.5 MW maximum onsite generation → Not feasible for FHL

b) Rule 21: The export limit is 1 MW → Storage must be added for onsite generation above 2.5 MW → High storage cost

c) Wholesale Distribution Access Tariff (WDAT): Market participation will be possible through WDAT and policy limits will be lifted. The interaction will be limited by physical constraints of the substation hardware → >10 MW power exchange is possible → Market participation will bring revenues for the site

In summary:

- With the ESTCP project: Optimization-based smart market participation (with WDAT) enables integration of large capacities of onsite generation and brings revenues through market participation.
- Without the ESTCP project: Onsite generation above 2.5 MW must be stored (at great cost), due to Rule 21 limitation.

The ESTCP/DER-CAM project provides market participation functionality, ancillary services, demand response, and energy imbalance market interaction with the California ISO, which can generate income, a policy goal of the Army to improve microgrid economics – this functionality is not in Corps scope for the microgrid