# Microgrid Modelling with DER-CAM

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DER-CAM DECISION SUPPORT TOOL FOR DECENTRALIZED ENERGY SYSTEMS
ANALYTICS | PLANNING | OPERATIONS

U.S. DEPARTMENT OF ENERGY

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Partners: Massachusetts Institute of Technology (MIT), EPRI, Metropolitan Washington Council of Governments, Brookhaven National Laboratory, Fort Hunter Liggett, TriTechnic, MIT Lincoln Laboratory, University of New Mexico, Public Service New Mexico, Universidad Pontificia Comillas – IIT, Xcogen Energy LLC, CSIRO, NEC

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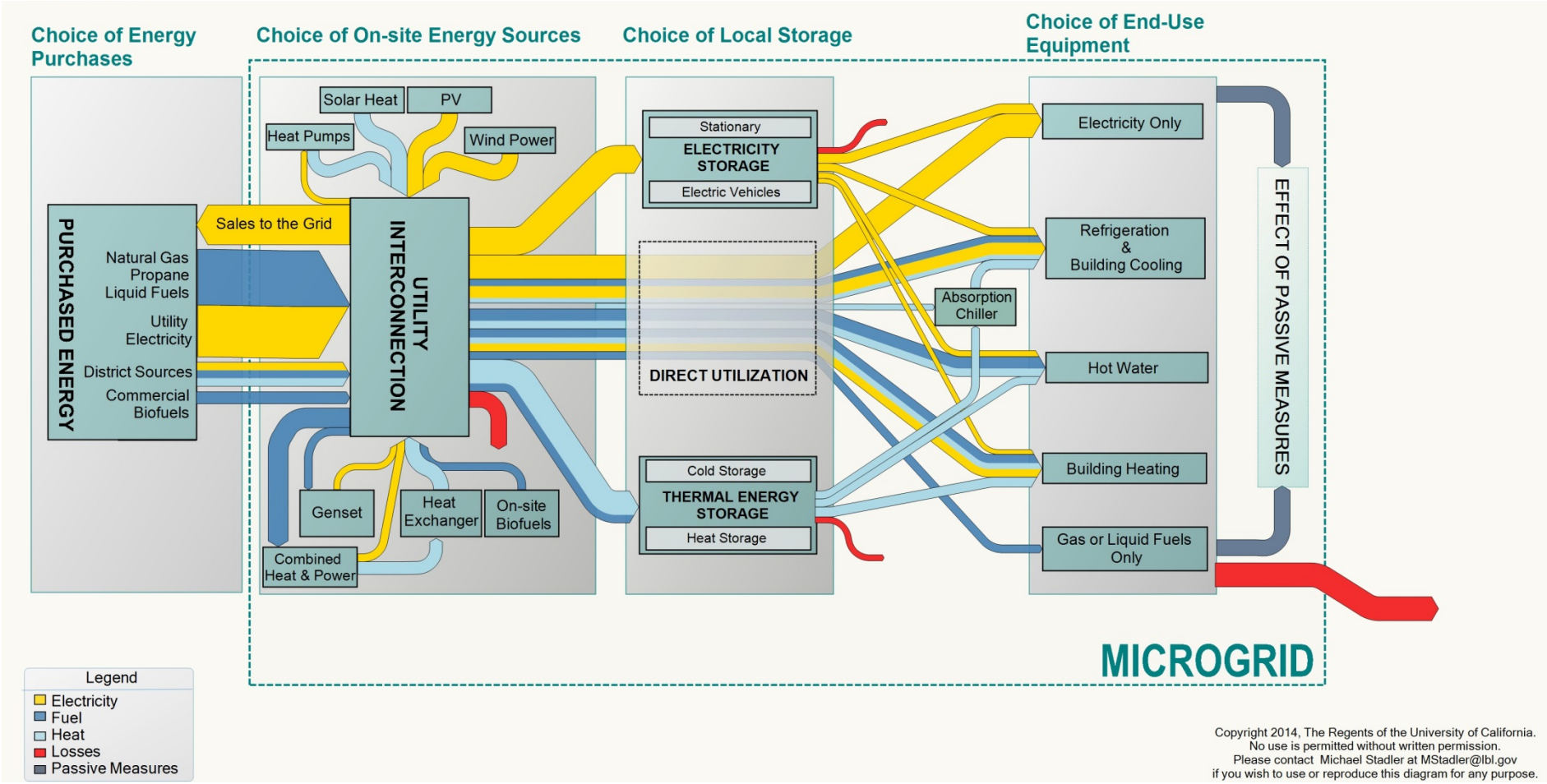
# Global Model for Microgrids

## Microgrid Architecture and Decision Making with DER-CAM

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# Distributed Energy Resources Customer Adoption Model (DER-CAM)

- is a deterministic and stochastic Mixed Integer Linear Program (MILP), written in the General Algebraic Modeling System (GAMS®)
- started as a building CHP optimization tool 13 years ago
- supported by the U.S. DOE, OE, DoD, CEC, private industry
- two main objective functions:
  - cost minimization
  - $CO_2$ minimization
- other objectives are possible, as well as multi-objective subject to microgrid/building constraints and energy balance
- produces optimal investment and dispatch results for biogas/diesel/natural gas CHP, fuel cells, ICE, micro-turbines, gas-turbines; PV, solar thermal, hot and cold water storage, batteries, heat pumps, absorption chiller, EV, passive measures (insulation, window changes, etc..)

# DER-CAM DECISION SUPPORT TOOL FOR DECENTRALIZED ENERGY SYSTEMS

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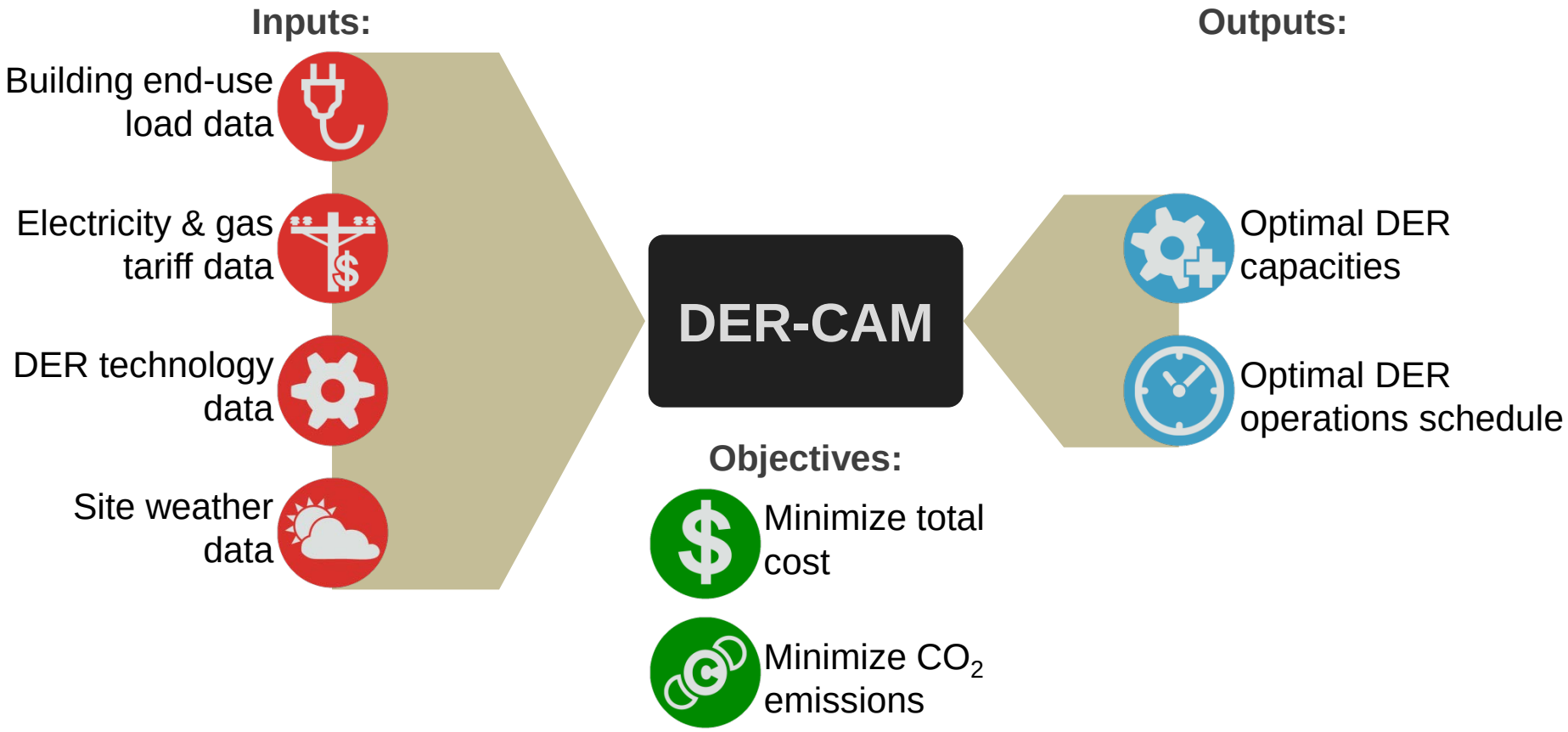
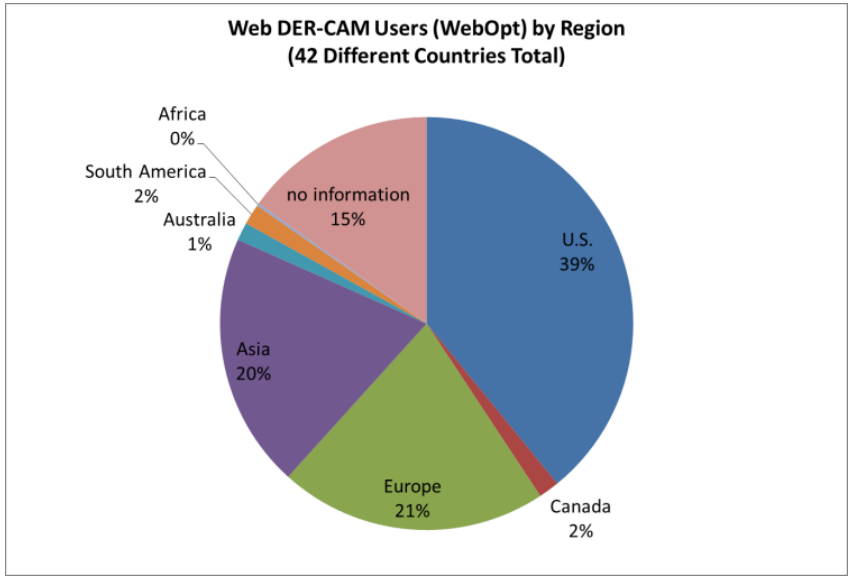
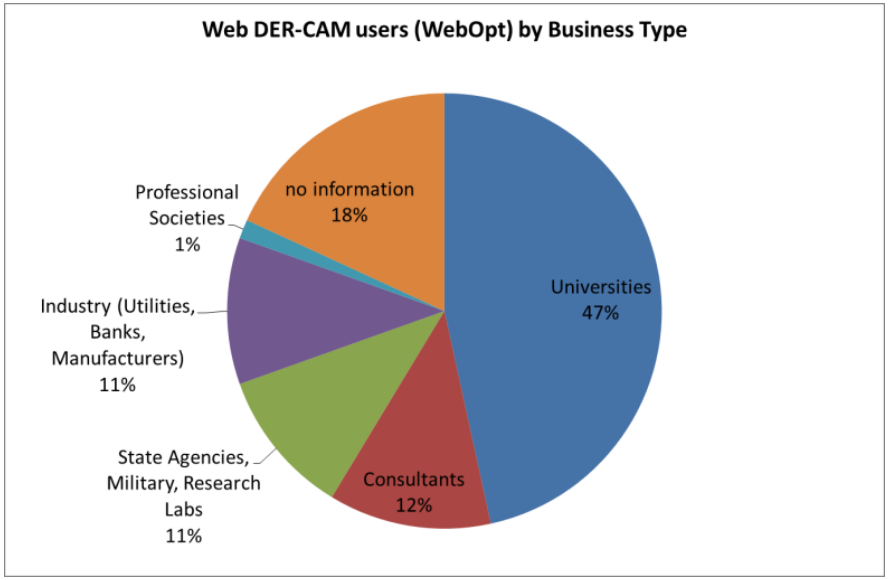



- **Investment & Planning:** determines optimal equipment combination and operation based on *historic* load data, weather, and tariffs → Microgrid Design Tool
- **Operations:** determines optimal week-ahead scheduling for installed equipment and *forecasted* loads, weather and tariffs→ Controller

## *DER-CAM Success*

- LBNL already started providing DER-CAM licenses and user base is growing fast
- DER-CAM has been proven by journal papers, reports, and field test (200 hits on Google)
- DER-CAM has been used as microgrid design tool by private entities outside of LBNL



# DER-CAM DECISION SUPPORT TOOL FOR DECENTRALIZED ENERGY SYSTEMS

ANALYTICS | PLANNING | OPERATIONS

## *Our Partners and DER-CAM Licensees*

*Application*

# Microgrid Capabilities and Resiliency at Fort Hunter Liggett

## *Fort Hunter Liggett (FHL) – Test Case*

*Overview*

- training facility for combat support and combat service support units of the Army Reserve
- largest installation in the Army Reserve (> 165,000 acres)
- existing DER: 2MW PV + 1MWh battery
- future: Large (>1MW) PV and battery system
- together with Siemens and the U.S. Army

*Objective*

Enable Microgrid capabilities for short and medium-term outages

*DER-CAM Contribution*

- use DER-CAM to gauge optimal capacity of DER
  - consider additional PV and storage
  - backup generation
  - short vs. long duration blackouts
  - optimal DER capacity

## *Fort Hunter Liggett – DER-CAM Assessment*

Objective: Use DER-CAM to perform an assessment of optimal DER at FHL to enable microgrid capabilities. Focus on resilience against natural disasters.

- blackout cases: none, 3 h, 24 h, 7 days

- standard DER-CAM assessment (no blackouts):
  - existing DER (BAU)
  - existing DER + additional PV and storage
  - existing DER + additional DER (full DER-CAM technology range)

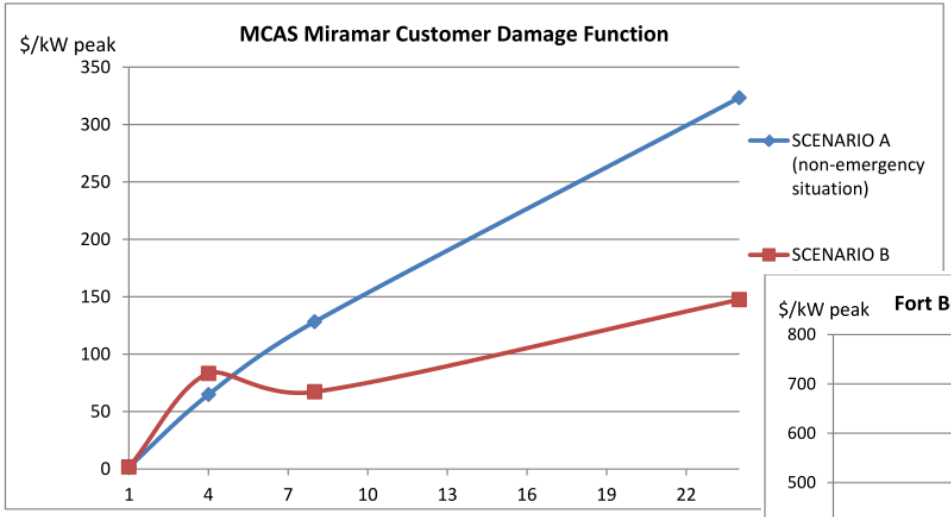
- DER-CAM assessment considering blackouts:
  - existing DER (BAU)
  - existing DER + additional PV and storage
  - existing DER + Diesel backup generators
  - existing DER + additional PV, batteries and diesel backup generators
  - existing DER + additional DER (full DER-CAM technology range)

Load prioritizations: 10% critical loads; 20% low priority; 70% medium priority

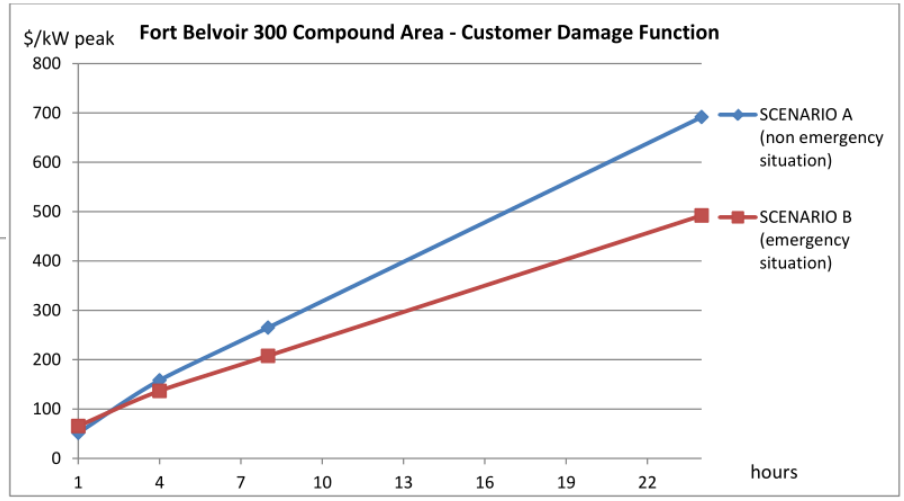
## *Customer Damage Function (CDF)*

Customer Damage Function is used to estimate outage costs as a function of the outage duration.

*Value of Electrical Energy Security (VEES) ~ Outage Duration * $/kW peak * Peak Demand*




*Source*:
Valuing Energy Security: Customer Damage Function Methodology and Case Studies at DoD Installations, NREL



## *Fort Hunter Liggett – Standard DER-CAM Assessment - no blackouts*

Key Results*)

| | BAU/Actual | Additional PV + Storage | All possible DER in DER-CAM |
|---|---|---|---|
| Annual Total Costs, million USD | 3.035 | 2.948 | 2.701 |
| Annual $CO_2$ emissions, ton | 4967 | 4161 | 4454 |
| Photovoltaic, kW | 2000 | 3032 | 2069 |
| Electric Storage, kWh | 1000 | 4141 | 1251 |
| ICE, kW | - | - | 2000 |
| CHP: ICE + HX, kW | - | - | 500 |
| Absorption Chiller, kW | - | - | 2828 |
| Solar Thermal, kW | - | - | 784 |

- allowing additional PV and storage shows that the optimal investment capacity is higher, which is in accordance with the existing expansion plans of FHL
- allowing other DER shows potential to reduce energy costs by up to 11% and $CO_2$ reductions by 10%

*) Sales are not part of this analysis

## *Fort Hunter Liggett – DER-CAM Assessment – with 3h blackout*

Key Results*)

| (Costs in million USD) | Existing PV and Storage | Existing PV, Storage + Diesel Backup | Additional PV and Storage | Additional PV, Storage and Diesel Backup | All DER |
|---|---|---|---|---|---|
| TOTAL COSTS | 3.050 | 3.043 | 2.948 | 2.948 | 2.701 |
| Electricity Costs | 2.218 | 2.218 | 1.703 | 1.692 | 1.147 |
| Fuel Costs | 0.320 | 0.320 | 0.320 | 0.320 | 0.475 |
| Annualized Capital Costs | 0.491 | 0.493 | 0.915 | 0.926 | 0.974 |
| O&M Costs | 0.001 | 0.001 | 0.001 | 0.001 | 0.035 |
| CDF Costs | 0.015 | 0.005 | - | - | - |
| Annual $CO_2$, ton | 4966 | 4967 | 4177 | 4161 | 4455 |
| *Installed capacity* | | | | | |
| Photovoltaic, kW | 2000 | 2000 | 3079 | 3032 | 2068 |
| Electric Storage, kWh | 1000 | 1000 | 3845 | 4141 | 1251 |
| Diesel Backup, kW | - | 200 | - | - | - |
| ICE, kW | - | - | - | - | 2000 |
| ICE HX, kW | - | - | - | - | 500 |
| Absorption Chiller, kW | - | - | - | - | 2828 |
| Solar Thermal, kW | - | - | - | - | 783 |

- 3h blackout has little to no effect on results
- existing capacity can be dispatched to meet all electric loads during short duration blackouts (some backup generators already exist at FHL)

*) Sales are not part of this analysis

## *Fort Hunter Liggett – DER-CAM Assessment - 24h blackout*

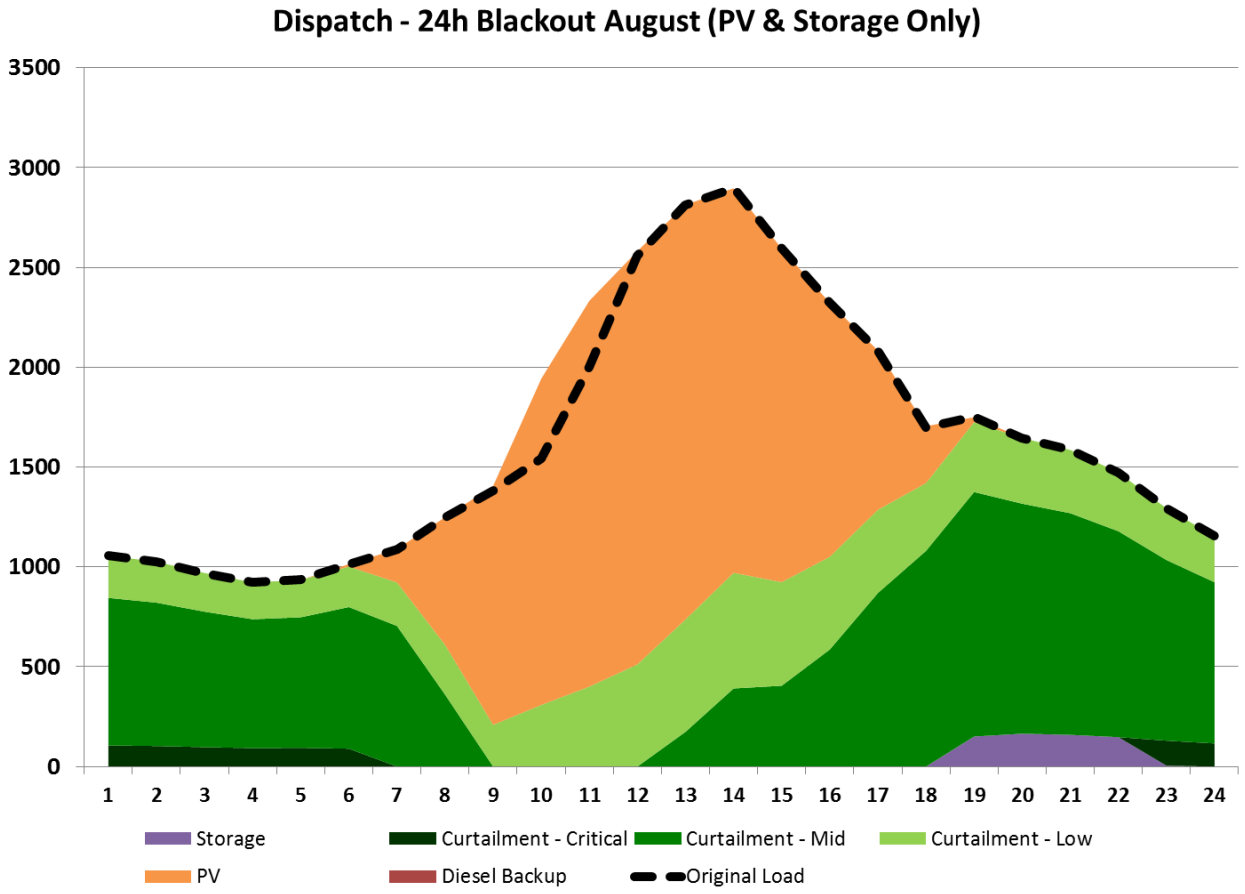
Key Results*)

| (Costs in million USD) | Existing PV and Storage | Existing PV, Storage + Diesel Backup | Additional PV and Storage | Additional PV, Storage and Diesel Backup | All DER |
|---|---|---|---|---|---|
| TOTAL COSTS | 5.363 | 3.068 | 3.655 | 2.976 | 2.702 |
| Electricity Costs | 2.216 | 2.216 | 0.785 | 1.661 | 1.145 |
| Fuel Costs | 0.320 | 0.326 | 0.320 | 0.324 | 0.477 |
| Annualized Capital Costs | 0.491 | 0.510 | 2.475 | 0.971 | 0.976 |
| O&M Costs | 0.001 | 0.001 | 0.001 | 0.001 | 0.036 |
| CDF Costs | 2.330 | 0.009 | 0.059 | 0.010 | 0.000 |
| Annual $CO_2$, ton | 4955 | 4973 | 2132 | 4119 | 4444 |
| *Installed Capacity* | | | | | |
| Photovoltaic, kW | 2000 | 2000 | 4936 | 3106 | 2077 |
| Electric Storage, kWh | 1000 | 1000 | 20709 | 4374 | 1250 |
| Diesel Backup, kW | - | 1400 | - | 1000 | - |
| ICE, kW | - | - | - | - | 2000 |
| ICE HX, kW | - | - | - | - | 500 |
| Absorption Chiller, kW | - | - | - | - | 2807 |
| Solar Thermal, kW | - | - | - | - | 801 |

- results show that additional PV and storage, in addition to backup generation, will allow FHL to survive 24h outages without any major service disruption at low costs – diesel consumption roughly 1250 gallon for 24h
- when considering all DER options, the optimal investment solution allows enough flexibility to maintain operation during 24h outages and lowest costs

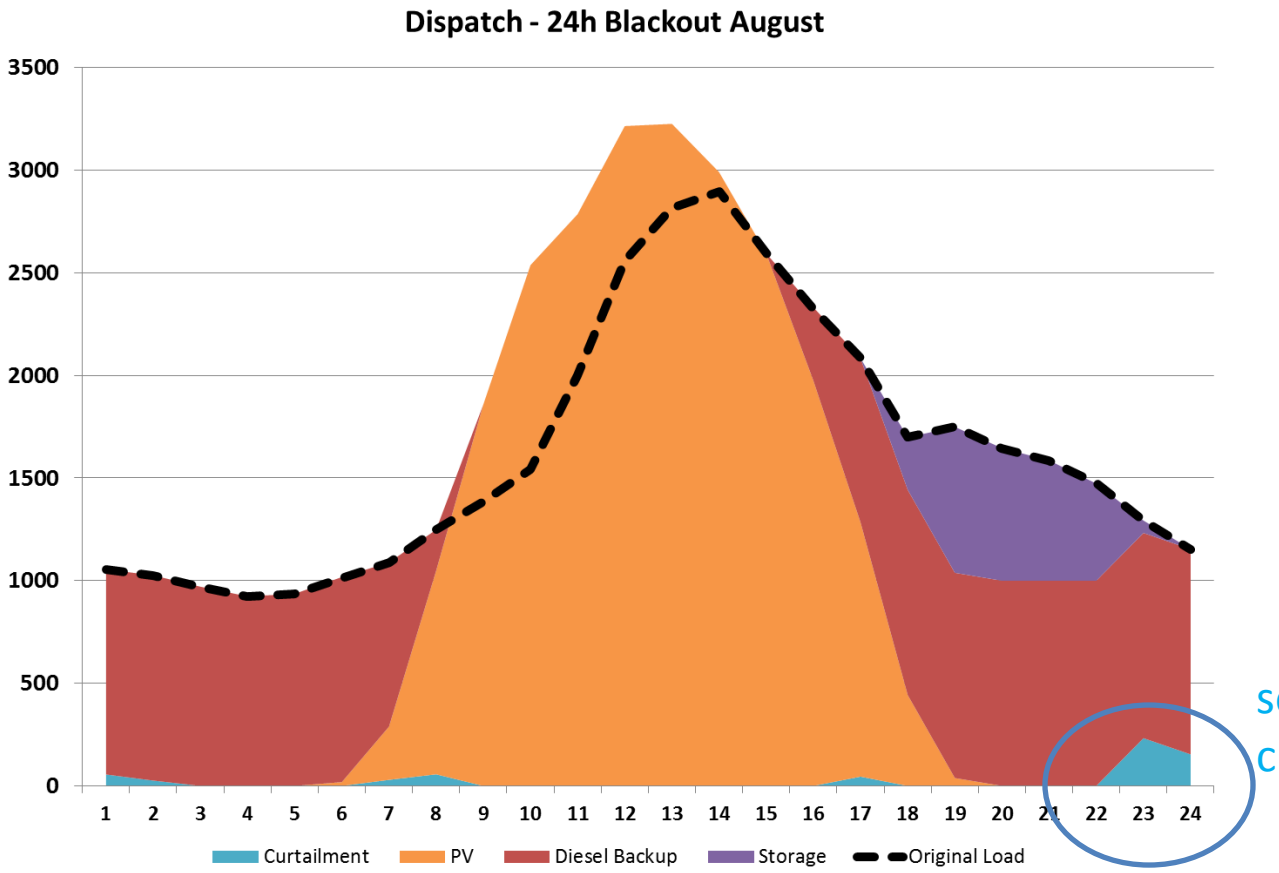
*) Sales are not part of this analysis

## *Fort Hunter Liggett – 24h blackout*




with the current PV and storage capacity alone, FHL would have severe curtailments in the event of a 24h outage, and would not be able to supply all critical loads

## *Fort Hunter Liggett – 24h blackout*




only PV, Batteries, and Backup Generators allowed

some load curtailment

planned expansion of PV and Storage, together with Diesel backup generators will allow increased resilience at FHL

## *Fort Hunter Liggett – 7 day blackout*

- extremely high costs in prolonged outages with current resources (with existing equipment 24 million USD, all DER allowed only 3 million USD)
- additional backup capacity increases significantly (up to 8 MW)
- considering the capacity of DER to be implemented at FHL, the ability to maintain operation during prolonged blackout periods relies only on the size of fuel storage (fuel storage sizing) – consumption during blackouts approx. 3300 gallon LNG for 7 days

## *Fort Hunter Liggett – Main conclusions of DER-CAM Assessment*

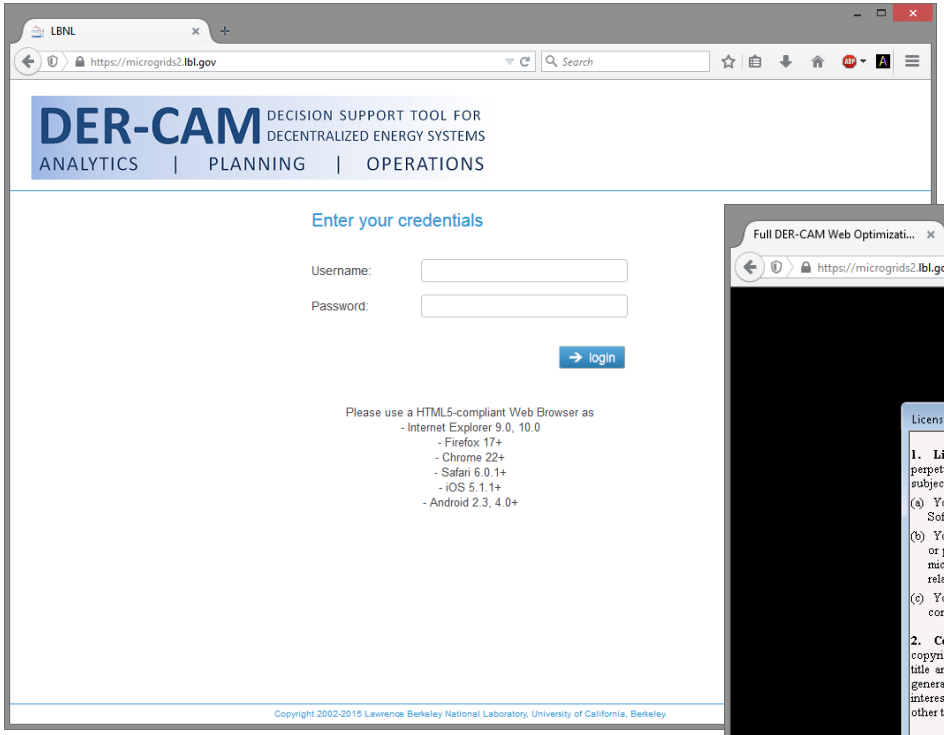
- the microgrid-enhanced DER-CAM capabilities are readily available and easy to use for assessing the optimal capacities in microgrids, with/without consideration of blackouts – both short and long duration
- using the microgrid & resilience features implemented in DER-CAM it is possible to get timely information on costs resulting from blackouts
- these features allow evaluating the readiness of candidate microgrid sites by estimating the costs of incremental investments required to build and operate in islanded mode
- the approach described in the FHL example is flexible, scalable and easily transferrable
- currently: trained DER-CAM person can achieve these results in less than 2 days of work

# *Demo*

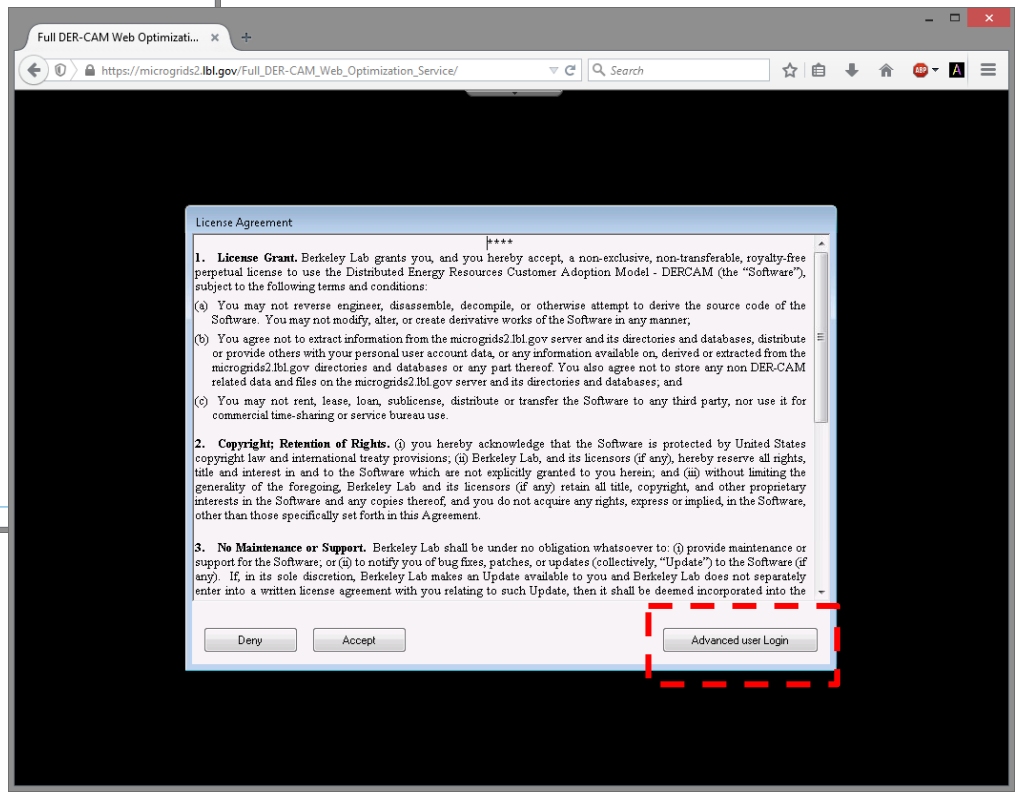
DER-CAM
DECISION SUPPORT TOOL FOR
DECENTRALIZED ENERGY SYSTEMS
ANALYTICS | PLANNING | OPERATIONS

# DER-CAM DECISION SUPPORT TOOL FOR DECENTRALIZED ENERGY SYSTEMS

ANALYTICS | PLANNING | OPERATIONS



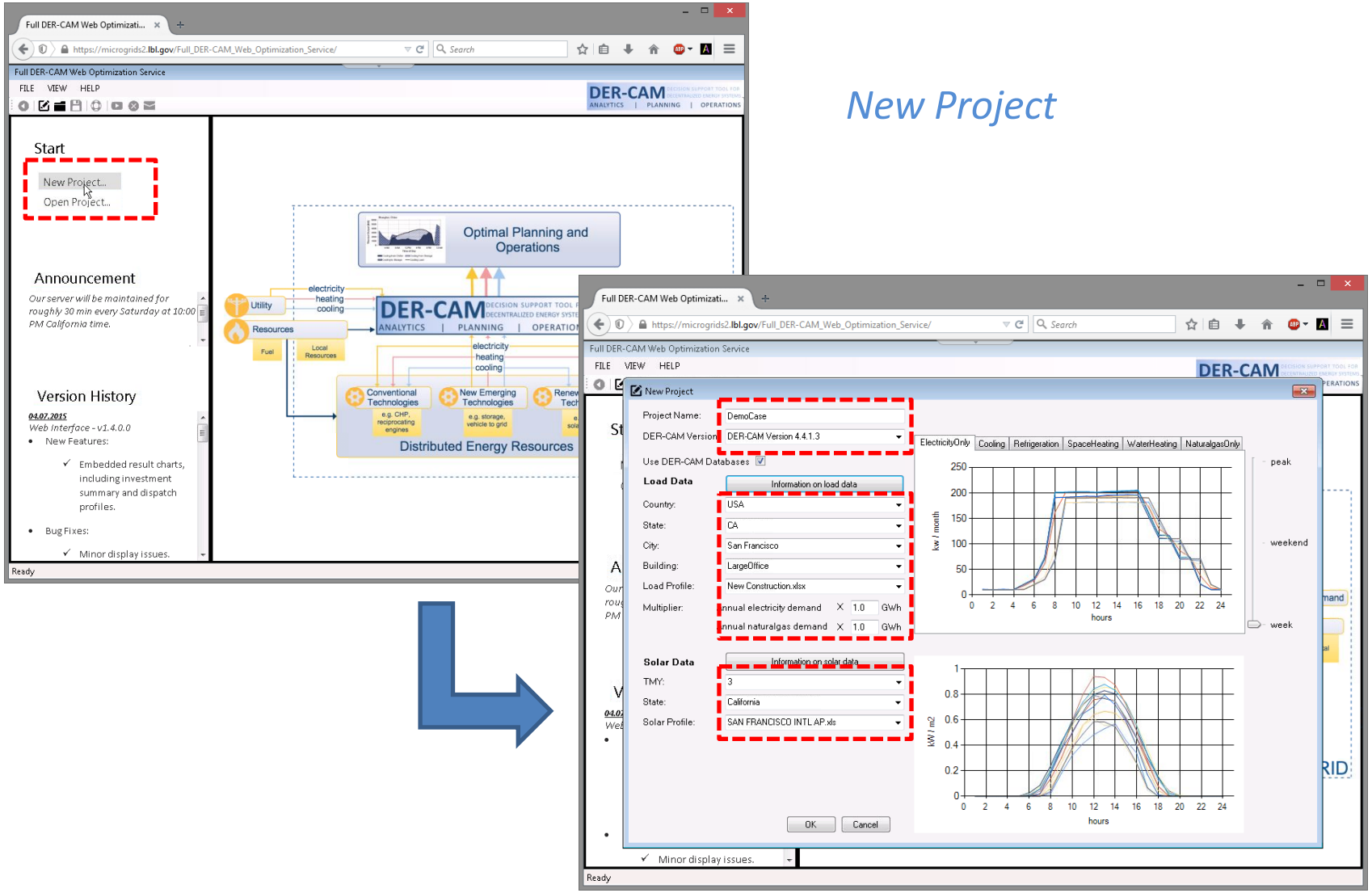

## *Login Screen*




Advanced user login allows access to customized versions

# DER-CAM DECISION SUPPORT TOOL FOR DECENTRALIZED ENERGY SYSTEMS

ANALYTICS | PLANNING | OPERATIONS

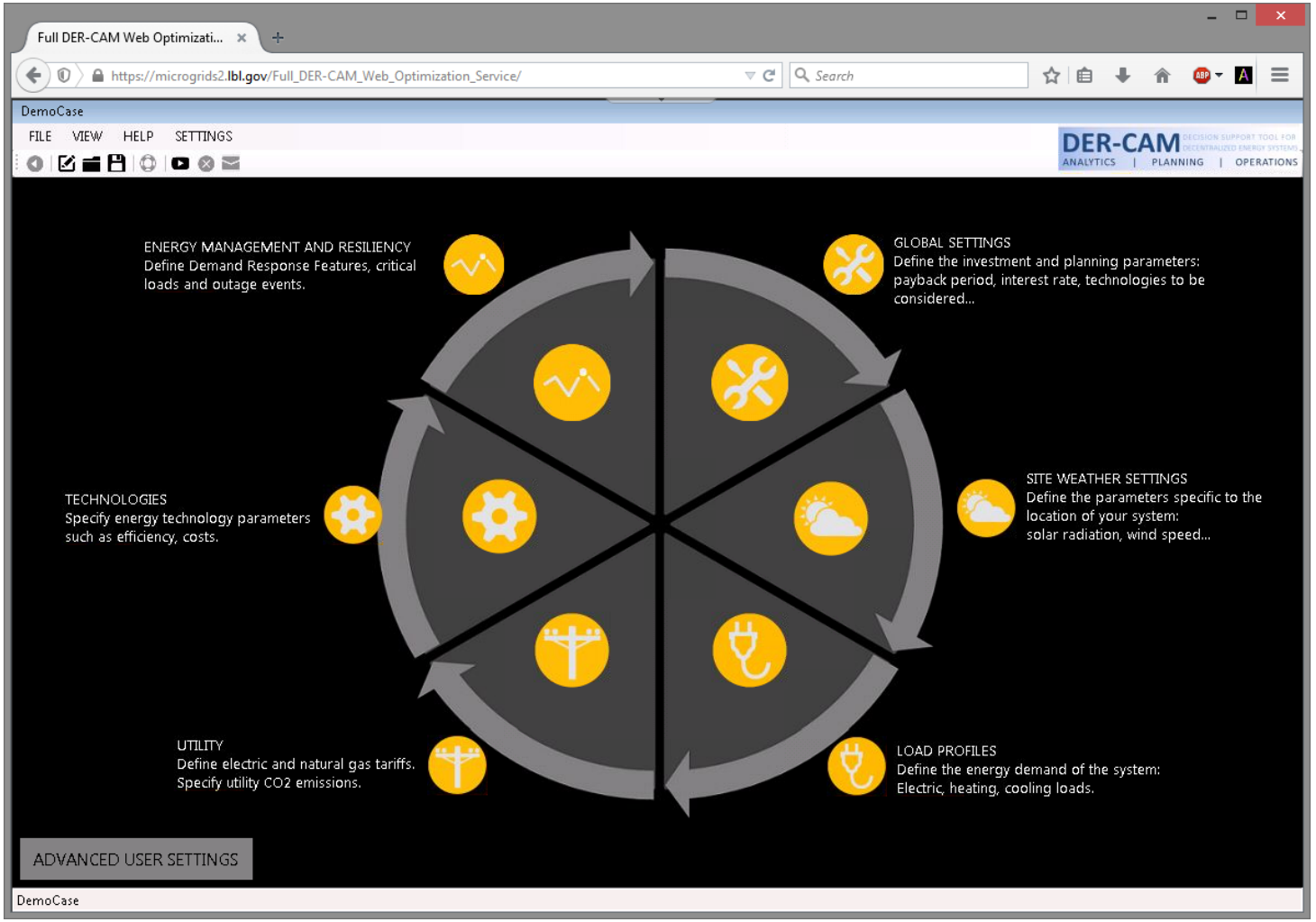


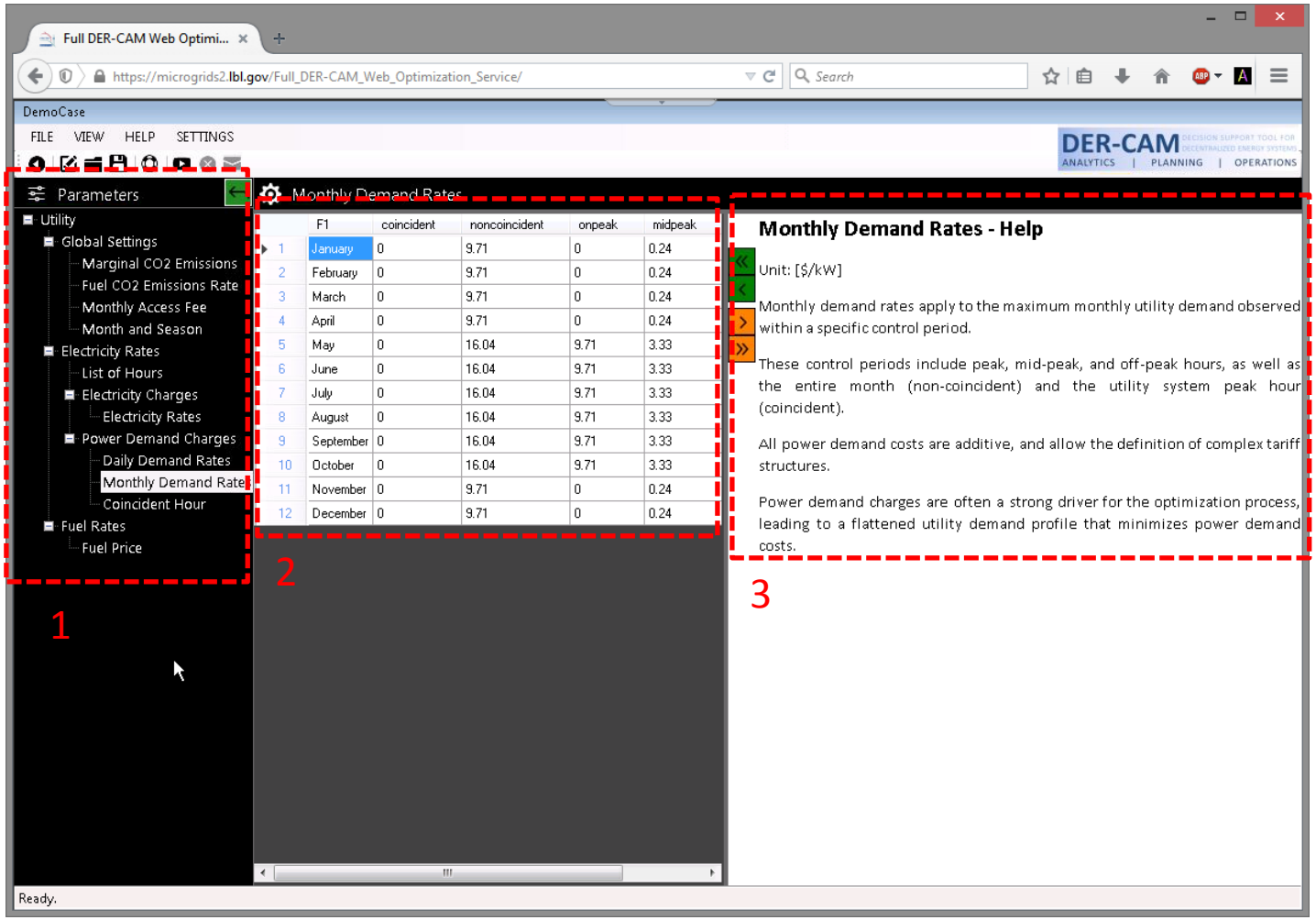

*New Project*

# DER-CAM DECISION SUPPORT TOOL FOR DECENTRALIZED ENERGY SYSTEMS

ANALYTICS | PLANNING | OPERATIONS

## *Model Overview*






*Model Overview: Closer Look at the Utility Sub-Menu*

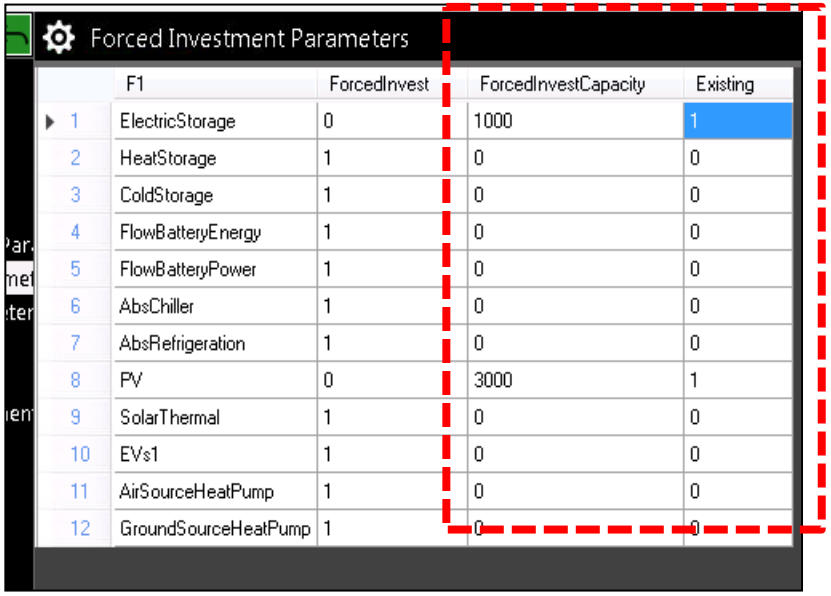
standard window structure: **1**: Table navigation ; **2**: Data input ; **3**: Help

## *Building a Model: Reference Case vs. Investment Case*

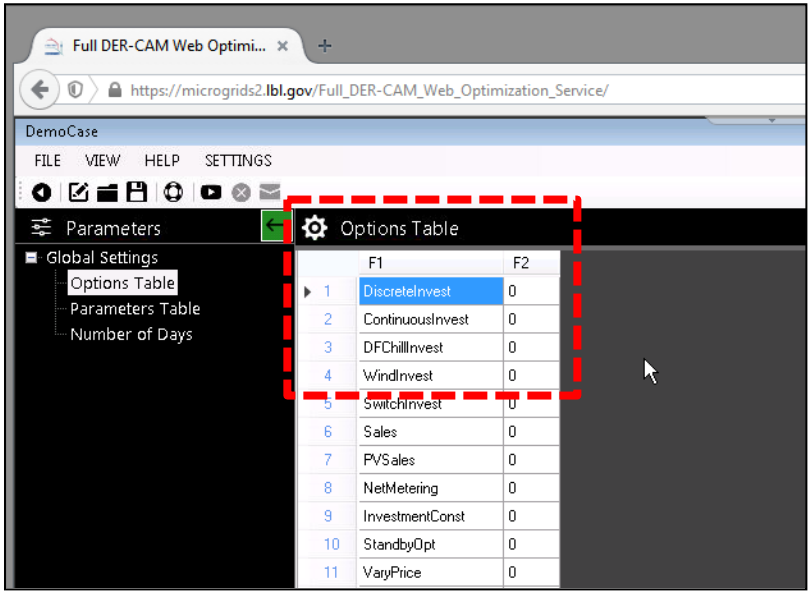
DER-CAM finds the optimal investment solution that satisfies several groups of constrains:

- energy balance (electric, heating, cooling, etc.)
- physical (rated capacity, conversion efficiency, available roof space, etc.)
- economic (discount rate, maximum payback period)

in order to satisfy the economic constrains, a **reference cost** must be obtained and the reference cost can be estimated by running DER-CAM with the existing infrastructure



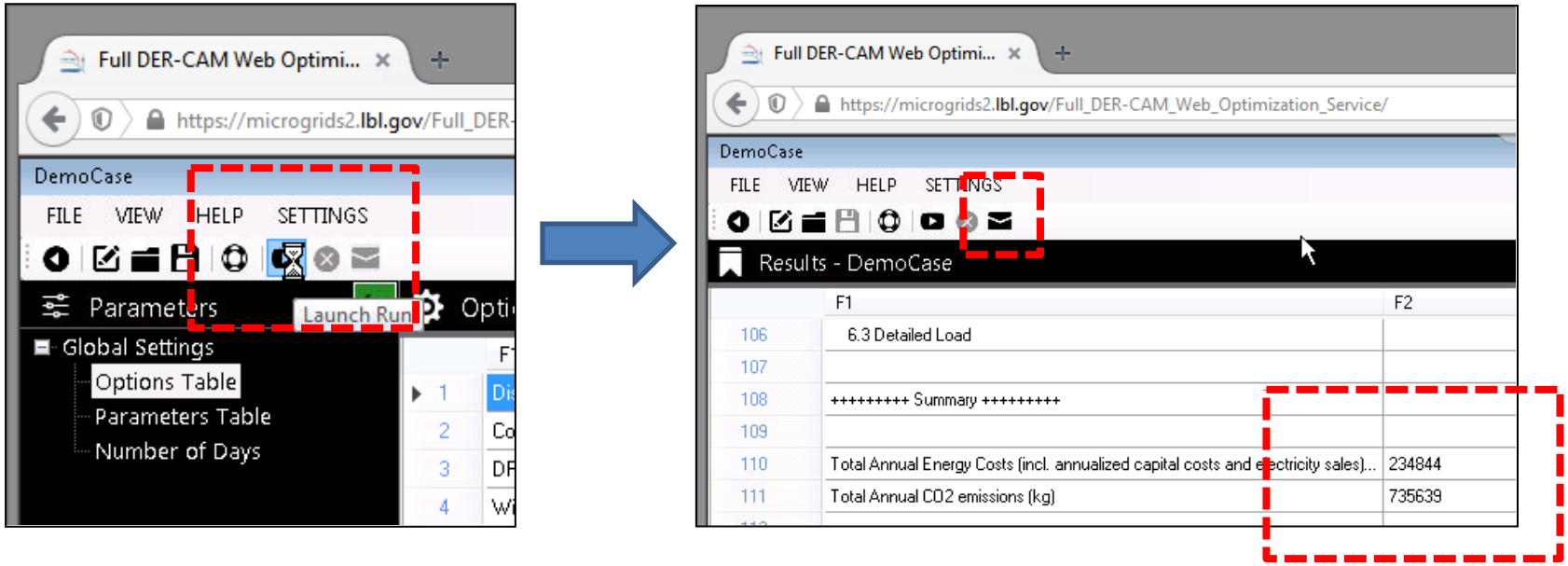

| | F1 | ForcedInvest | ForcedInvestCapacity | Existing |
|---|---|---|---|---|
| 1 | ElectricStorage | 0 | 1000 | 1 |
| 2 | HeatStorage | 1 | 0 | 0 |
| 3 | ColdStorage | 1 | 0 | 0 |
| 4 | FlowBatteryEnergy | 1 | 0 | 0 |
| 5 | FlowBatteryPower | 1 | 0 | 0 |
| 6 | AbsChiller | 1 | 0 | 0 |
| 7 | AbsRefrigeration | 1 | 0 | 0 |
| 8 | PV | 0 | 3000 | 1 |
| 9 | SolarThermal | 1 | 0 | 0 |
| 10 | EVs1 | 1 | 0 | 0 |
| 11 | AirSourceHeatPump | 1 | 0 | 0 |
| 12 | GroundSourceHeatPump | 1 | 0 | 0 |




| | F1 | F2 |
|---|---|---|
| 1 | DiscreteInvest | 0 |
| 2 | ContinuousInvest | 0 |
| 3 | DFChillInvest | 0 |
| 4 | WindInvest | 0 |
| 5 | SwitchInvest | 0 |
| 6 | Sales | 0 |
| 7 | PVSales | 0 |
| 8 | NetMetering | 0 |
| 9 | InvestmentConst | 0 |
| 10 | StandbyOpt | 0 |
| 11 | VaryPrice | 0 |

## *Building a Model: Reference Case vs. Investment Case*

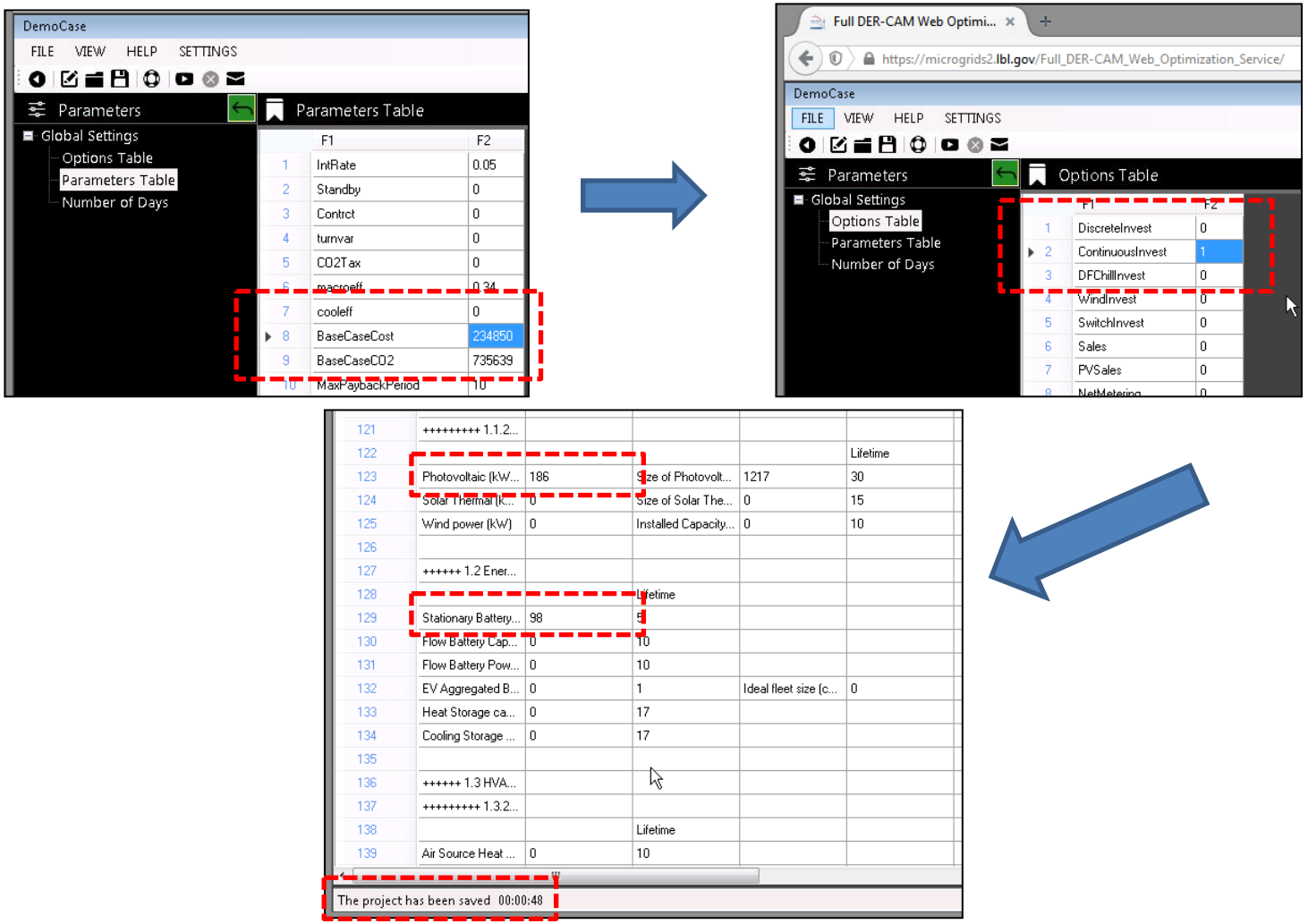
the total annual energy costs obtained in the reference case will then be used in the investment scenarios to allow estimating savings and return period of new investments



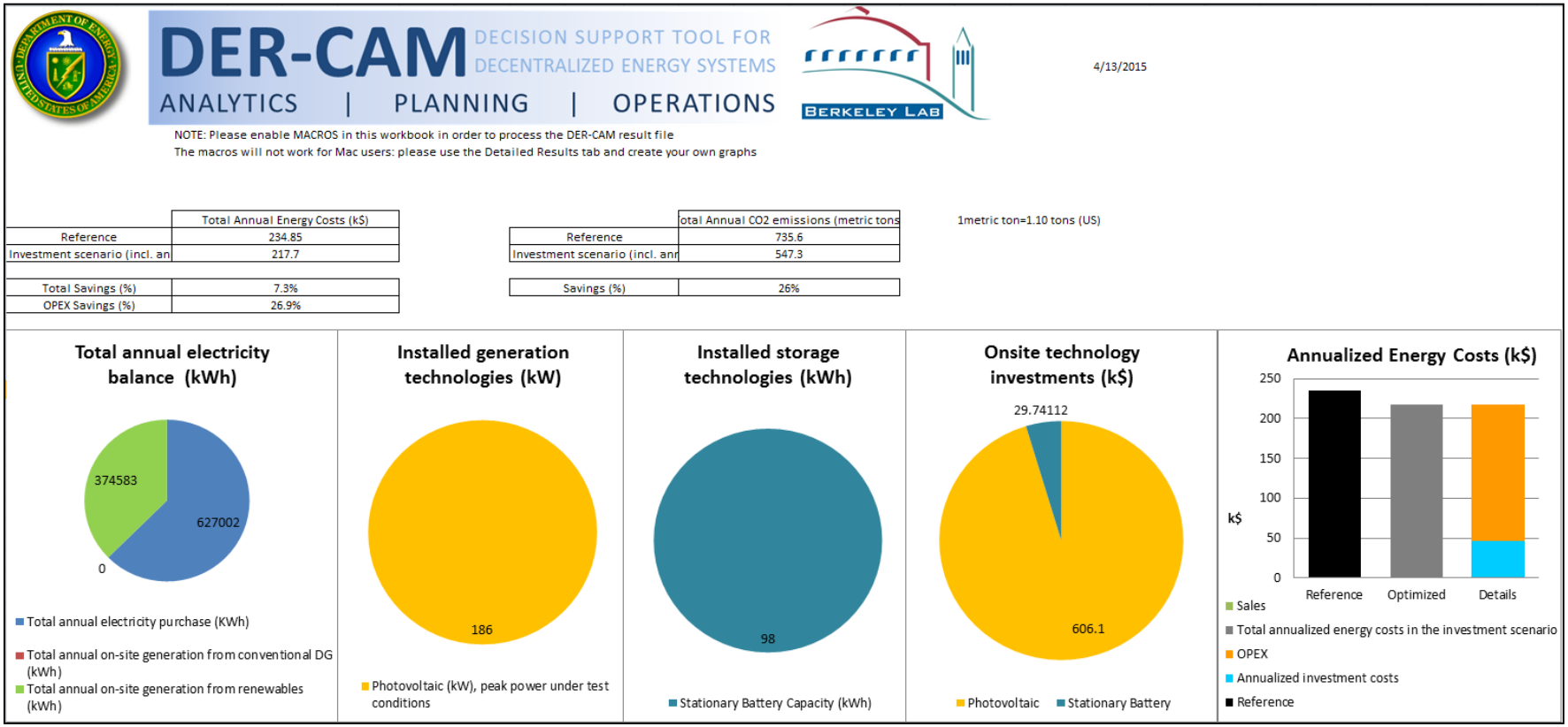

the results obtained in any run are stored on the server and can be sent via e-mail

## *Building a Model: Investment Case*

after updating the reference costs and CO2 emissions, an investment case can be performed



# *Building a Model: Results*



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4/13/2015

NOTE: Please enable MACROS in this workbook in order to process the DER-CAM result file
The macros will not work for Mac users: please use the Detailed Results tab and create your own graphs

| | Total Annual Energy Costs (k$) |
|---|---|
| Reference | 234.85 |
| Investment scenario (incl. an | 217.7 |

| | Total Savings (%) | 7.3% |
|---|---|---|
| | OPEX Savings (%) | 26.9% |

| | otal Annual CO2 emissions (metric tons |
|---|---|
| Reference | 735.6 |
| Investment scenario (incl. anr | 547.3 |

| | Savings (%) | 26% |
|---|---|---|

1metric ton=1.10 tons (US)

**Total annual electricity balance (kWh)**



**Installed generation technologies (kW)**



**Installed storage technologies (kWh)**

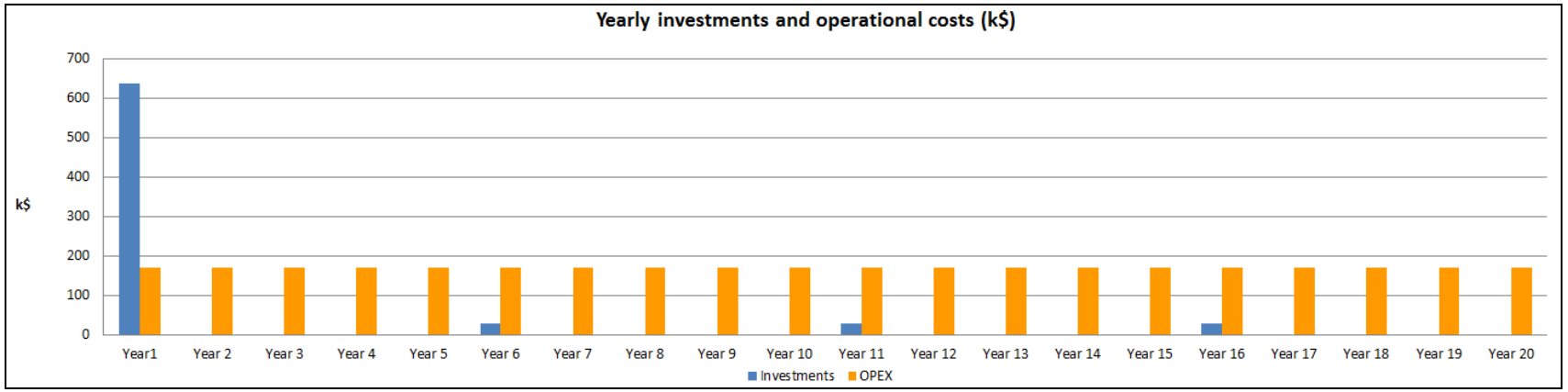


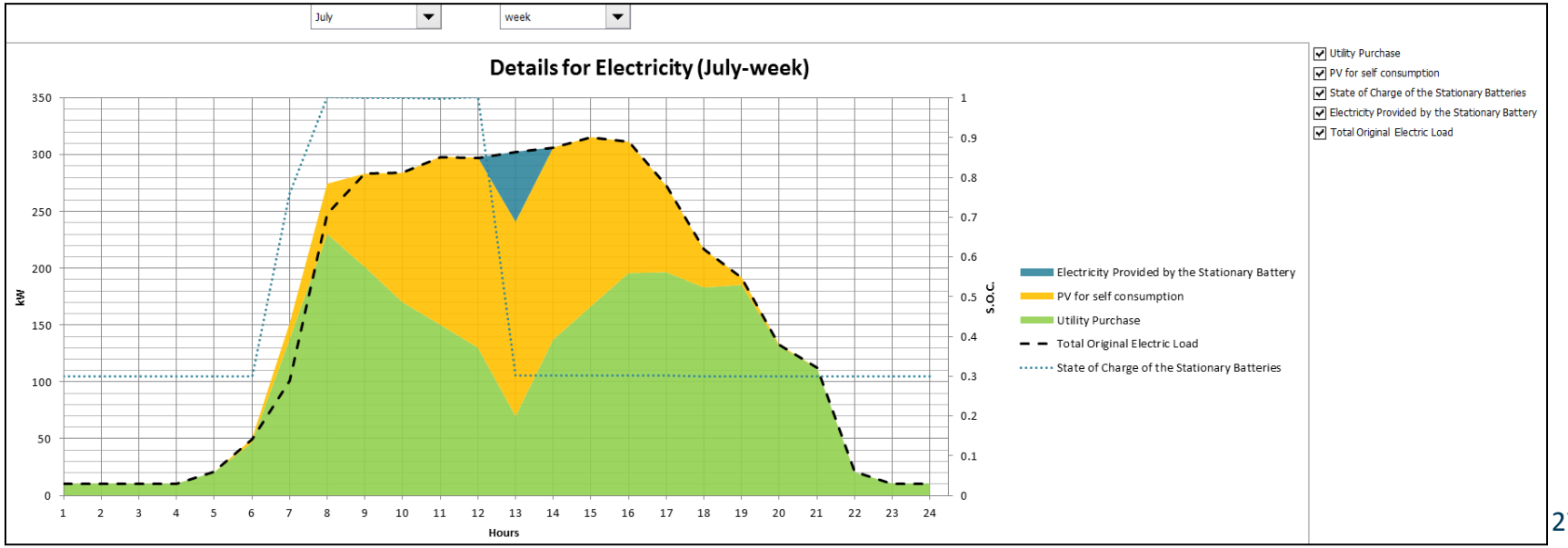
**Onsite technology investments (k$)**



**Annualized Energy Costs (k$)**

# *Building a Model: Results*



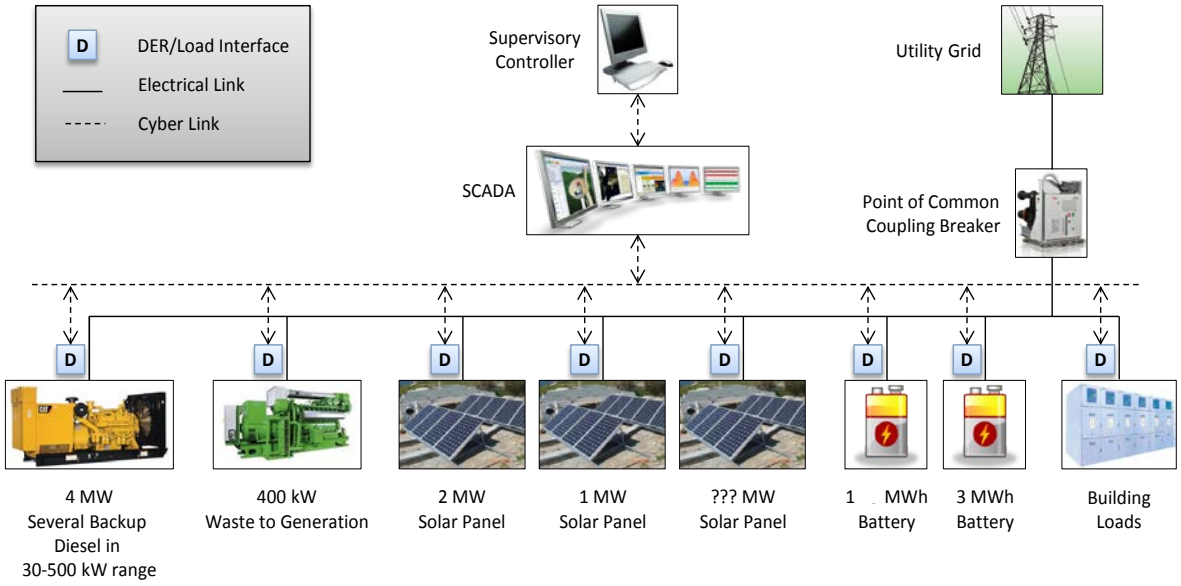
Questions and comments are very welcome!

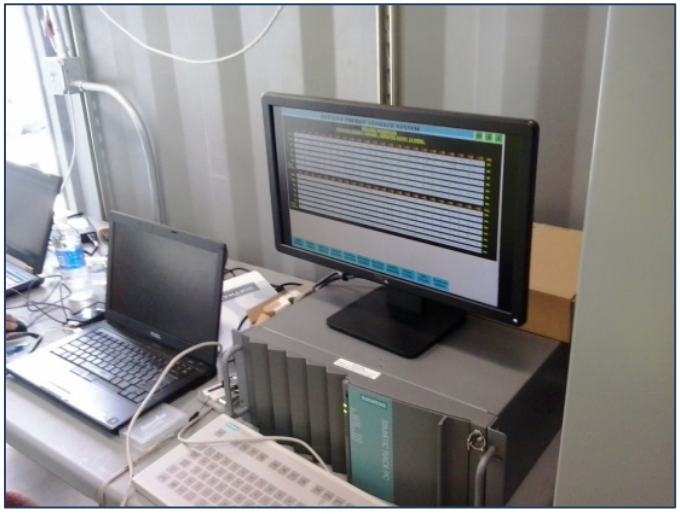
*Backup Slides*

# Microgrid Controller Work at Fort Hunter Liggett

# Fort Hunter Liggett – Technology Portfolio

- goal: use Operations DER-CAM based supervisory microgrid controller to optimize operation schedules and limit grid export
- current technologies: 2 MW of PV, 1 MWh battery, and 4 MW backup diesel,
- planned 2016: several MW of PV, 3 MWh battery, and 400 kW waste to generation



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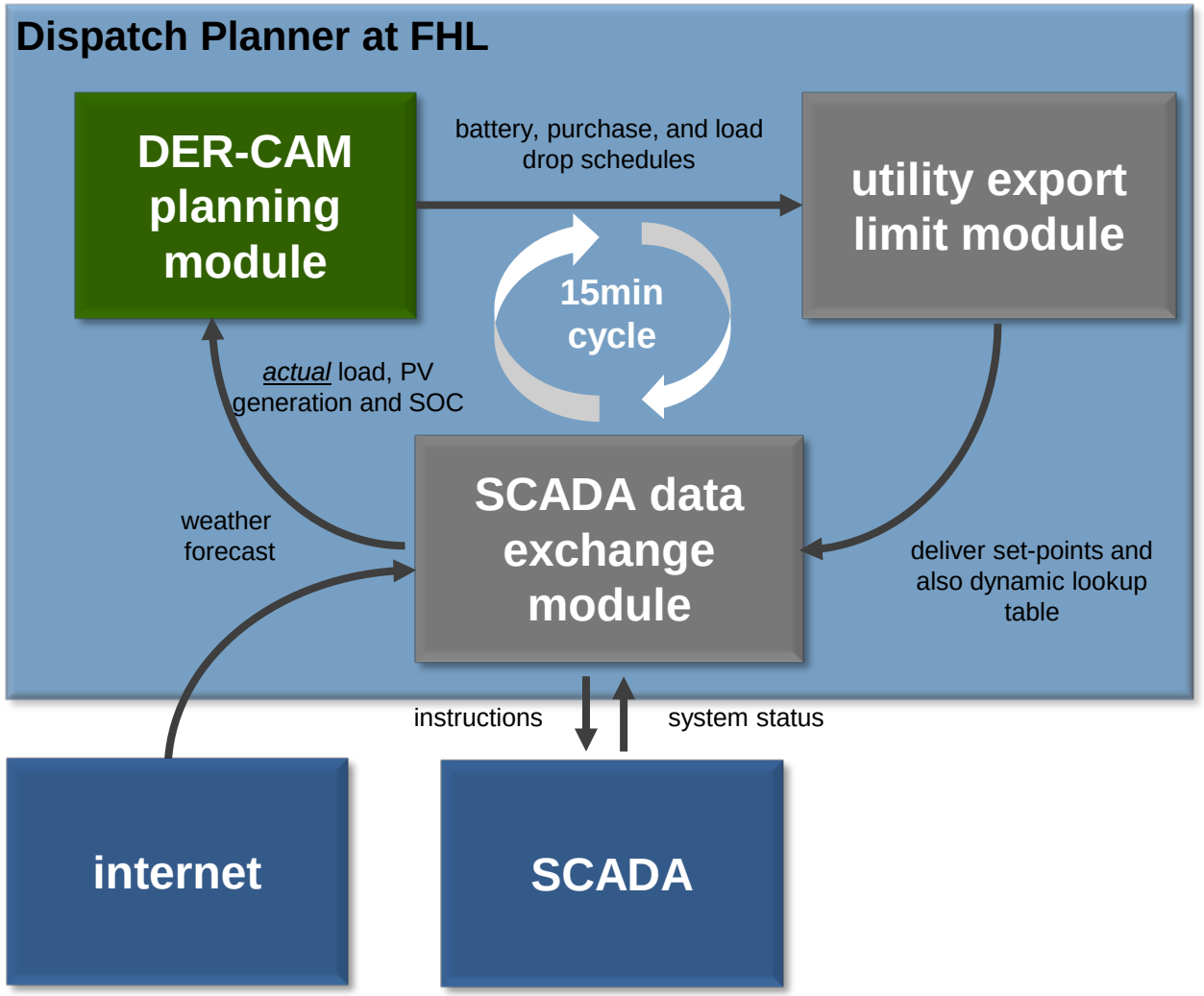
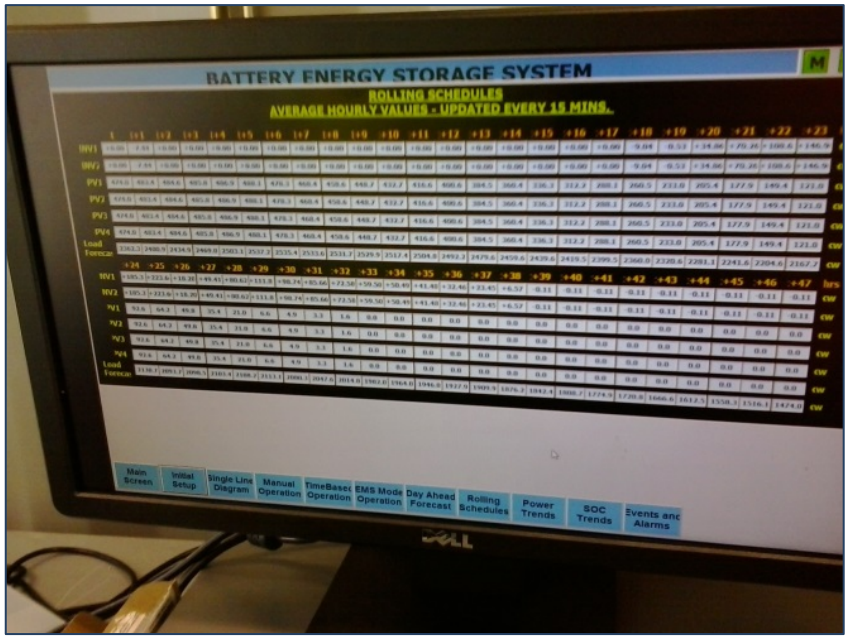
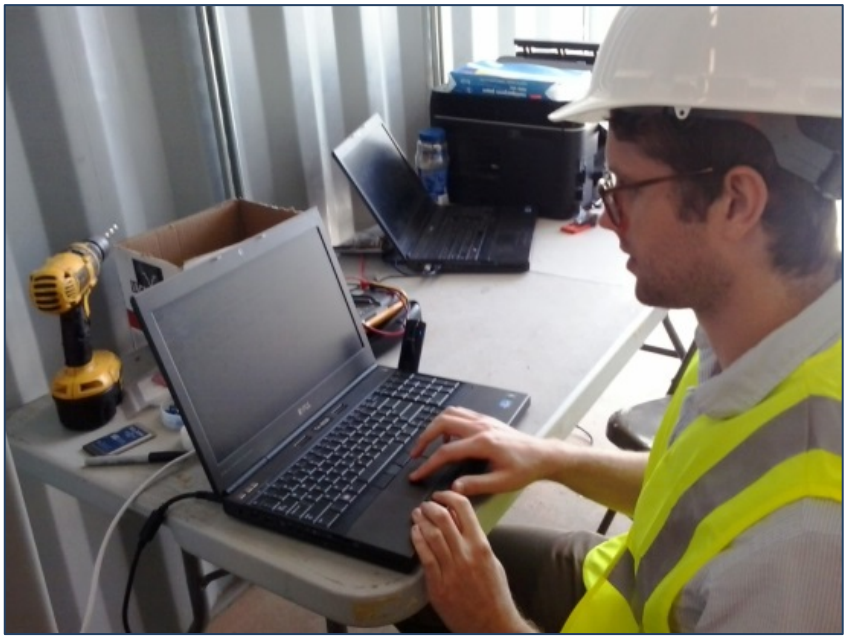
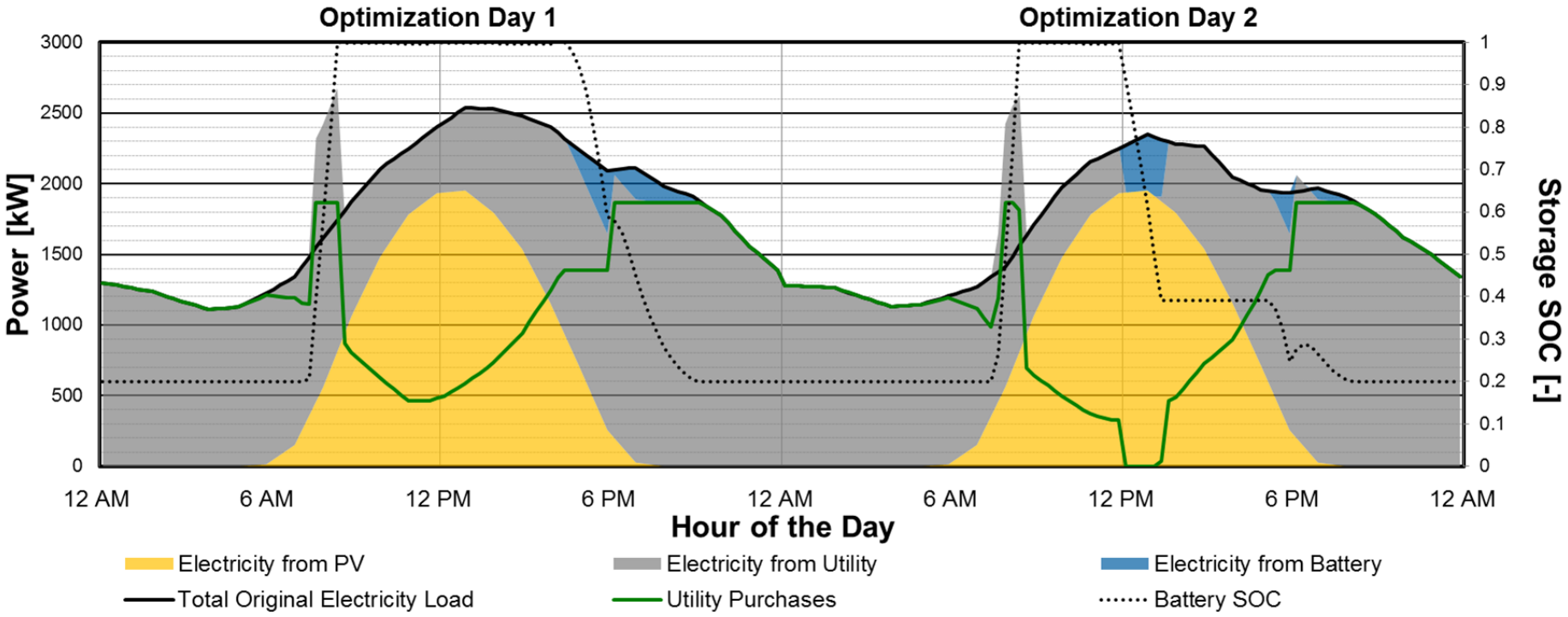


# Successful Feeding of Operations DER-CAM Dispatches into the SCADA System



- two-days ahead predictive optimization
- PV and load forecasts are inputs to Operations DER-CAM

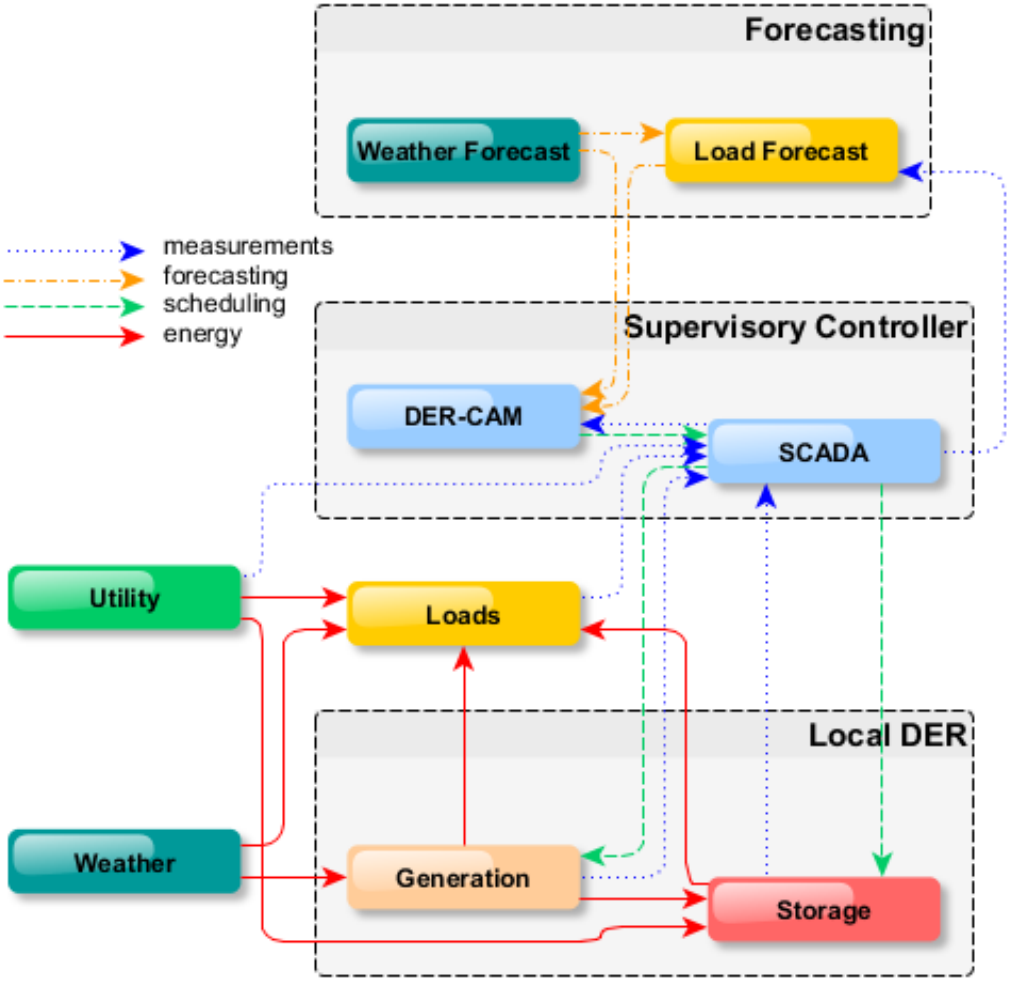


*Backup Slides*

# Multi-Layered Microgrid Controller with Utility Connectivity

# Utility and Microgrid Interactions

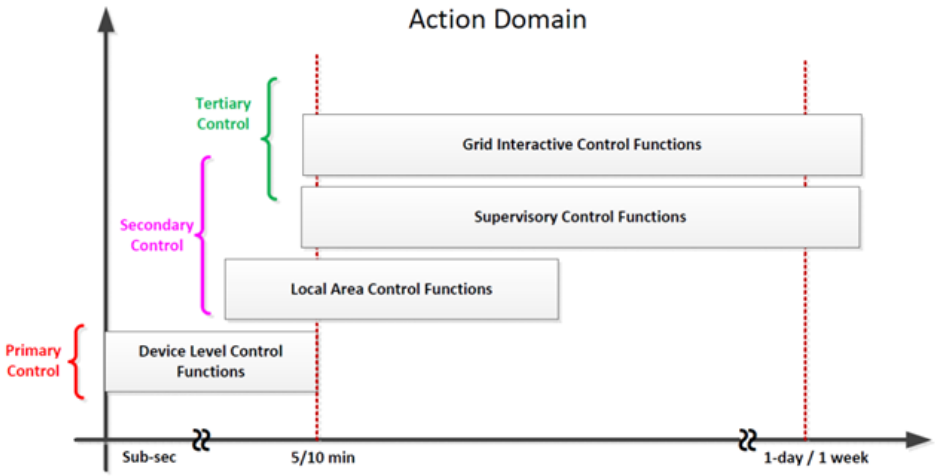
schematic of physical and cyber interactions between utility, microgrid site, local resources, microgrid controller, and optimization problem



# Layered Architecture for Utility-Interactive Microgrid

## Function Assignment

| | |
|---|---|
| **Block 4** | **Grid Interactive Control Functions**<br>(Area EPS control, Spot Market, DMS, TSCADA, Connection to adj. Microgrid) |
| **Block 3** | **Supervisory Control Functions**<br>(Forecasting, Data management and Visualization, Optimization [e.g. Volt/ VAR, Economic dispatch], Dispatch, State Estimation, Emergency Handling, Generation Smoothing, Spinning Reserve, Topology Change Management, Black Start, Protection Coordination) |
| **Block 2** | **Local Area Control Functions**<br>(Sequence Logic/Status control, Load Management, Building Energy Management, Plant Controller, AGC, Fast Load Shedding, Resynchronization, Disturbance Recording) |
| **Block 1** | **Device Level Control Functions**<br>(Voltage/Frequency Control, Reactive power Control, Electric Vehicle Control, Energy Storage Control, Load Control, Generation Control, Islanding Detection, Fault Protection) |



*Backup Slides*

# Implementation at Fort Hunter Liggett

# Introduction on Fort Hunter Liggett and Lessons Learned from USAG Vicenza Italy

Caserma Ederle/Del Din Microgrid with Central Energy Plant and Distributed Generation

- technical issues:
  - communication: isolated network
  - network certification: DIACAP now RMF
  - central power generation vs. distributed generation
  - reference signal
  - precise phase matching
  - harmonics
  - reacting faster than the grid

- saving money:
  - Microgrid, if implemented correctly can reduce implementation of future distributed energy generation and storage systems
  - distributed systems can reduce equipment number and sizes, increase reliability and reduce maintenance costs
  - DER-CAM logic can reduce energy costs with potential to make money

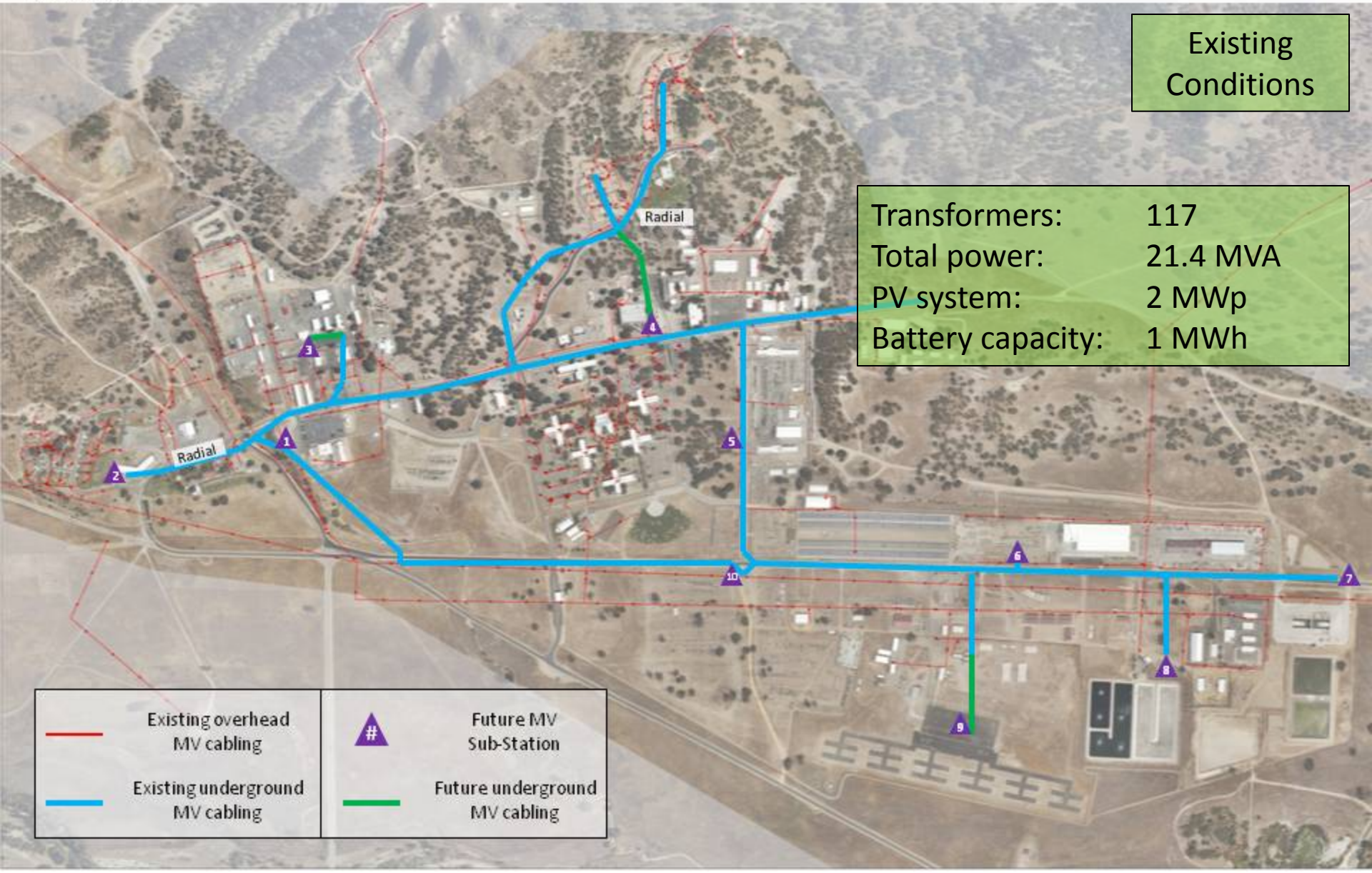
- Fort Hunter Liggett (FHL) currently has a centralized 2 (+1 under construction) MW PV and 1 MWh battery

- planning for Net-Zero: requires 8 to 9 MW PV

- planning for energy security: will require 16 MWh of battery for continues operation

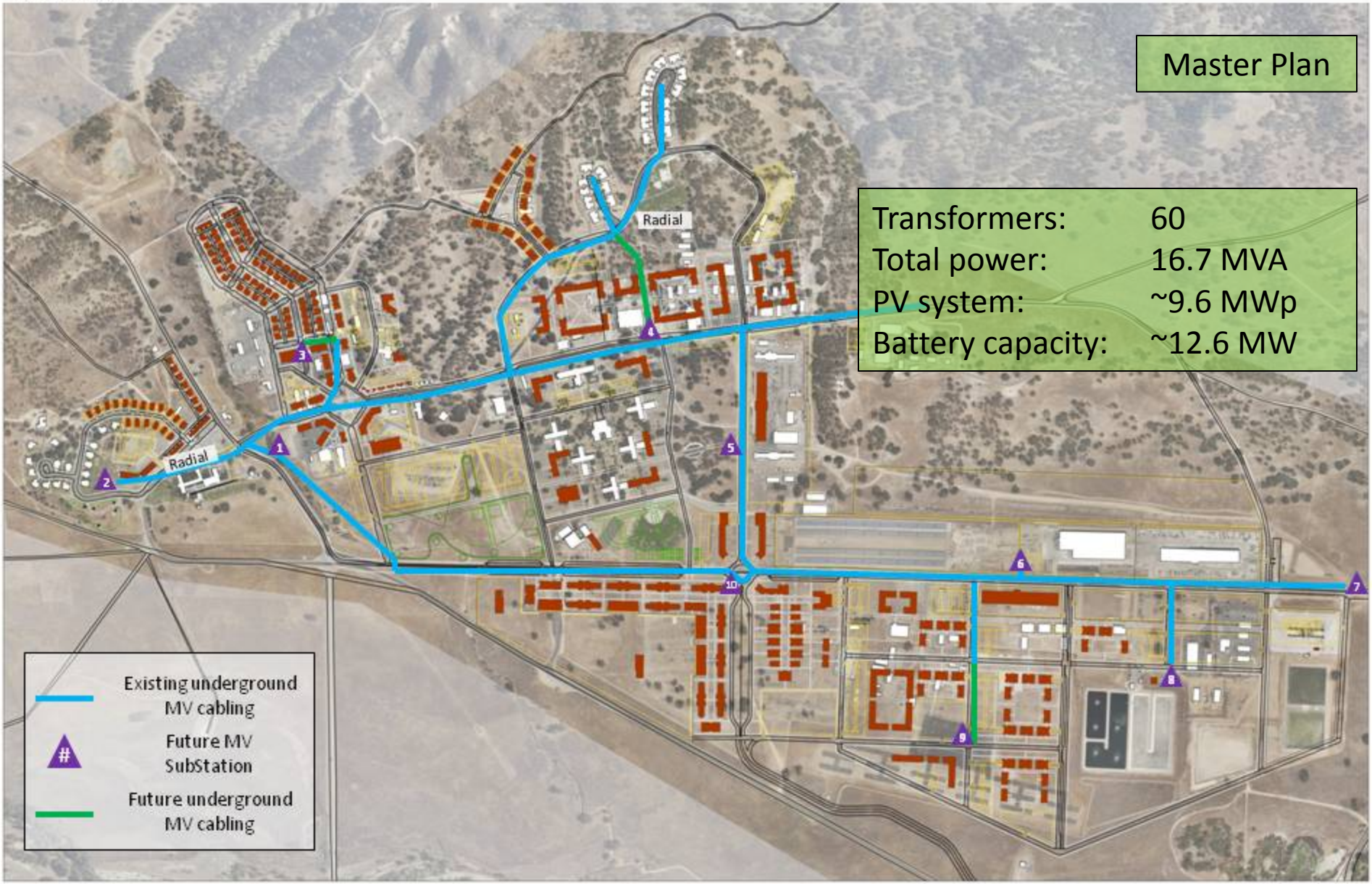
# US Army Garrison - Fort Hunter Liggett

## Micro Grid Concept Design



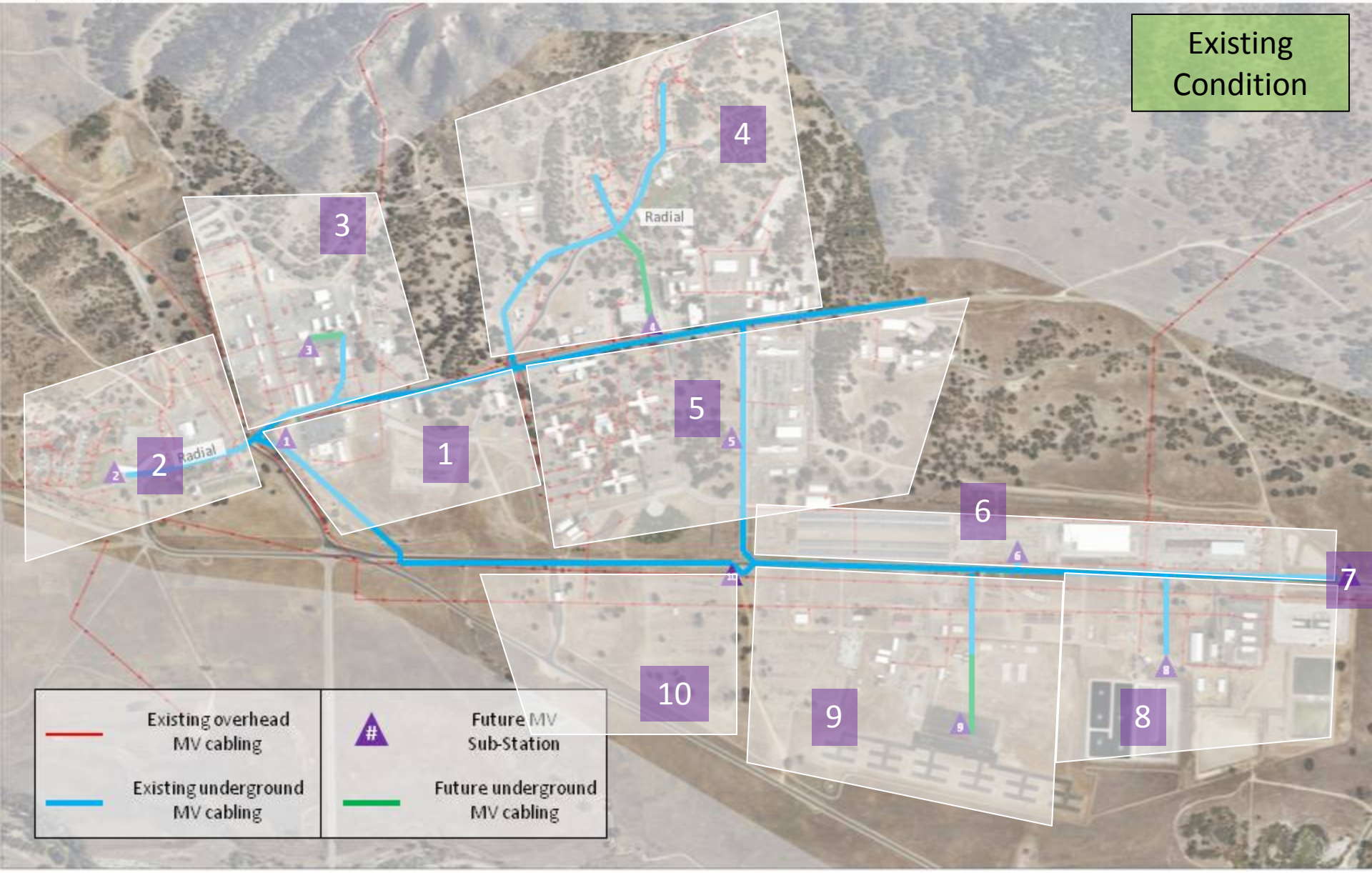
# US Army Garrison - Fort Hunter Liggett

## Micro Grid Concept Design



# US Army Garrison - Fort Hunter Liggett

## Micro Grid Concept Design

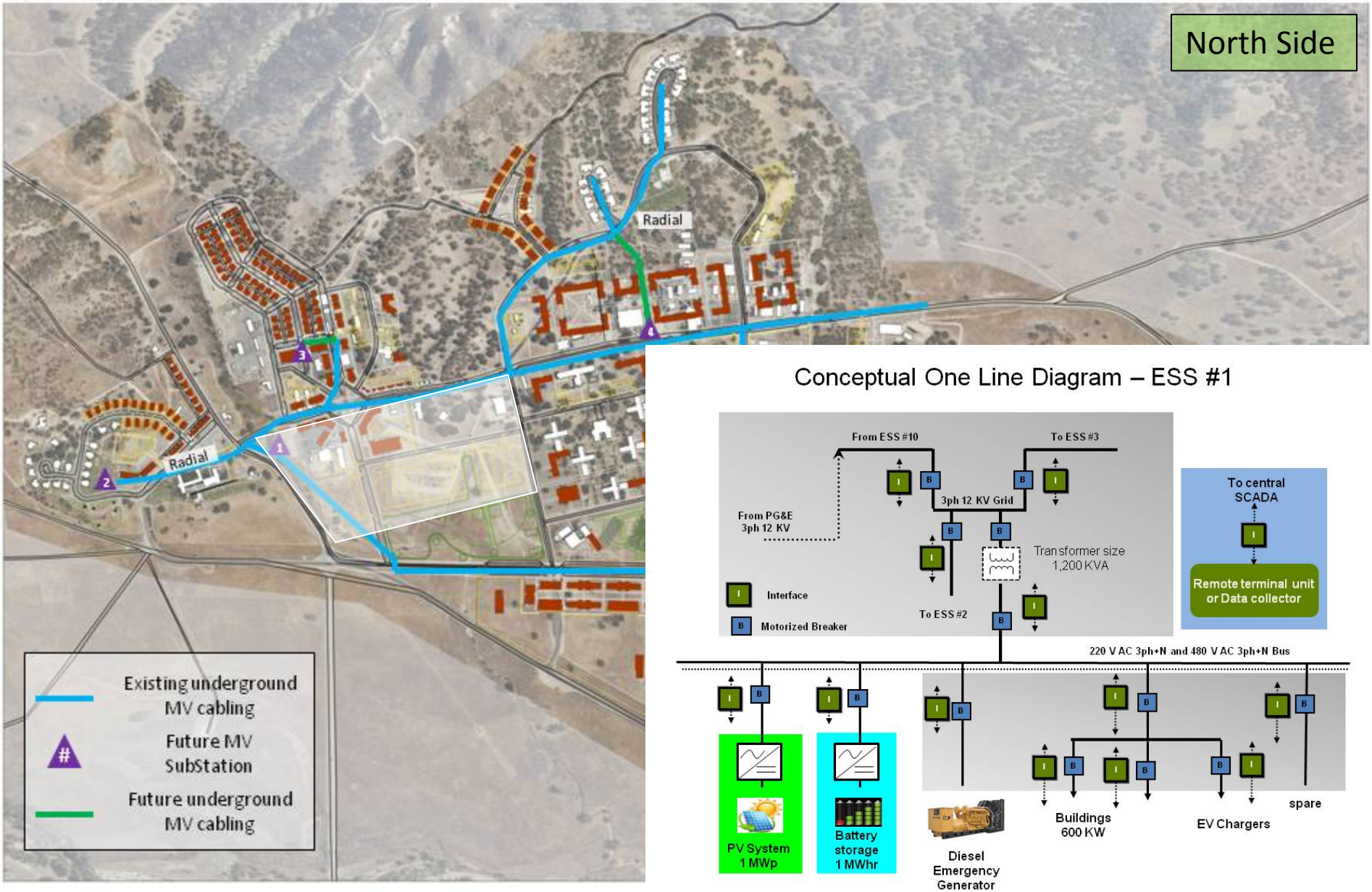


# US Army Garrison - Fort Hunter Liggett

## Micro Grid Concept Design

# US Army Garrison - Fort Hunter Liggett

## Micro Grid Concept Design

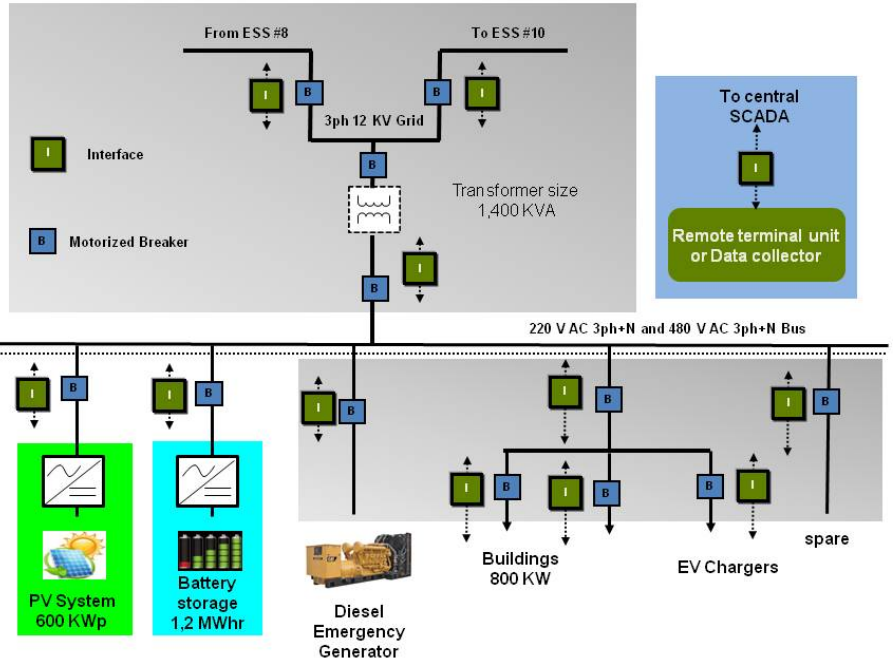



### Conceptual One Line Diagram – ESS #1

# US Army Garrison - Fort Hunter Liggett

# Micro Grid Concept Design

## Conceptual One Line Diagram – ESS #9




South Side

Existing underground MV cabling

Future MV SubStation

Future underground MV cabling

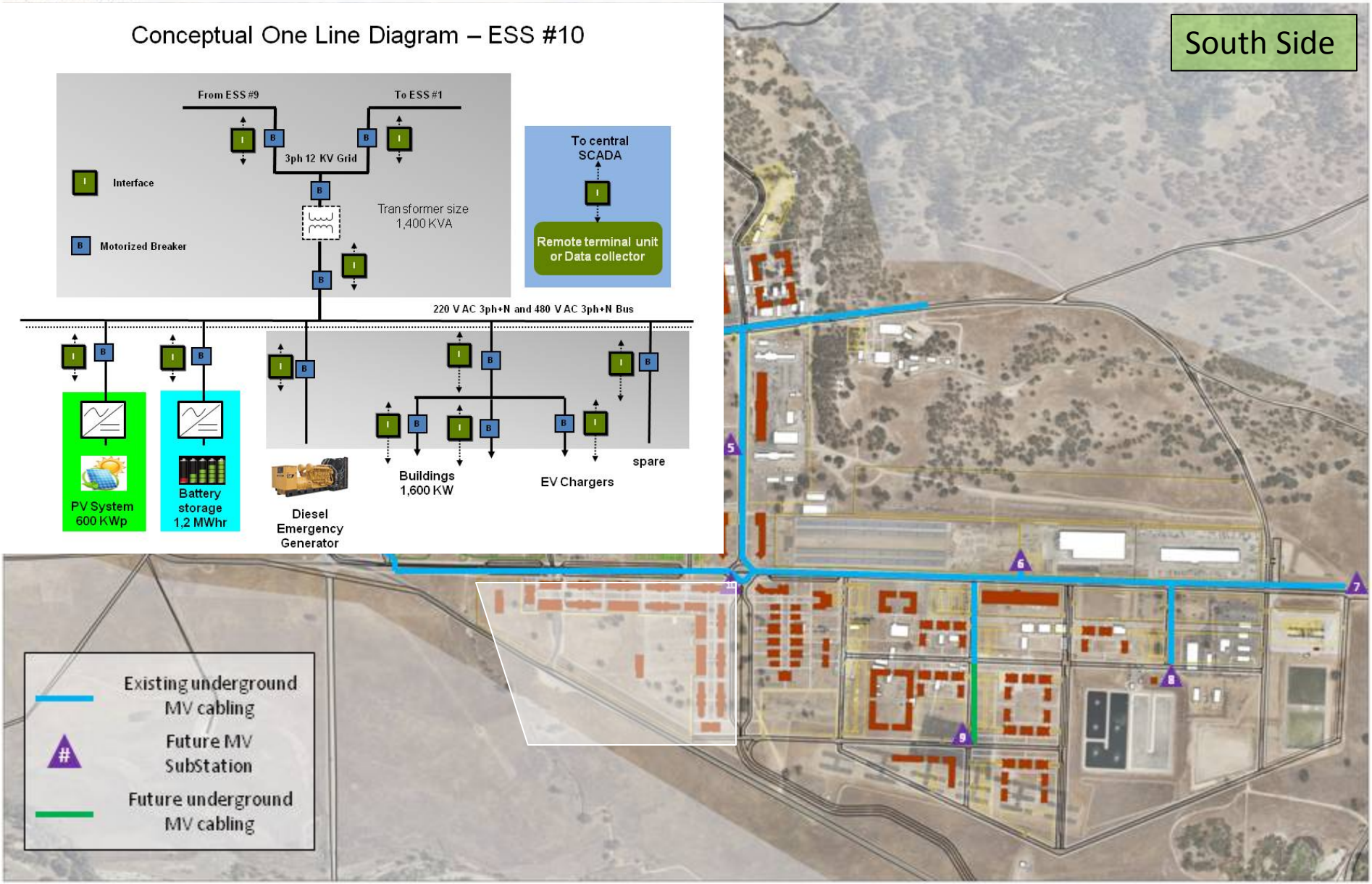
# US Army Garrison - Fort Hunter Liggett

## Micro Grid Concept Design

### Conceptual One Line Diagram – ESS #10

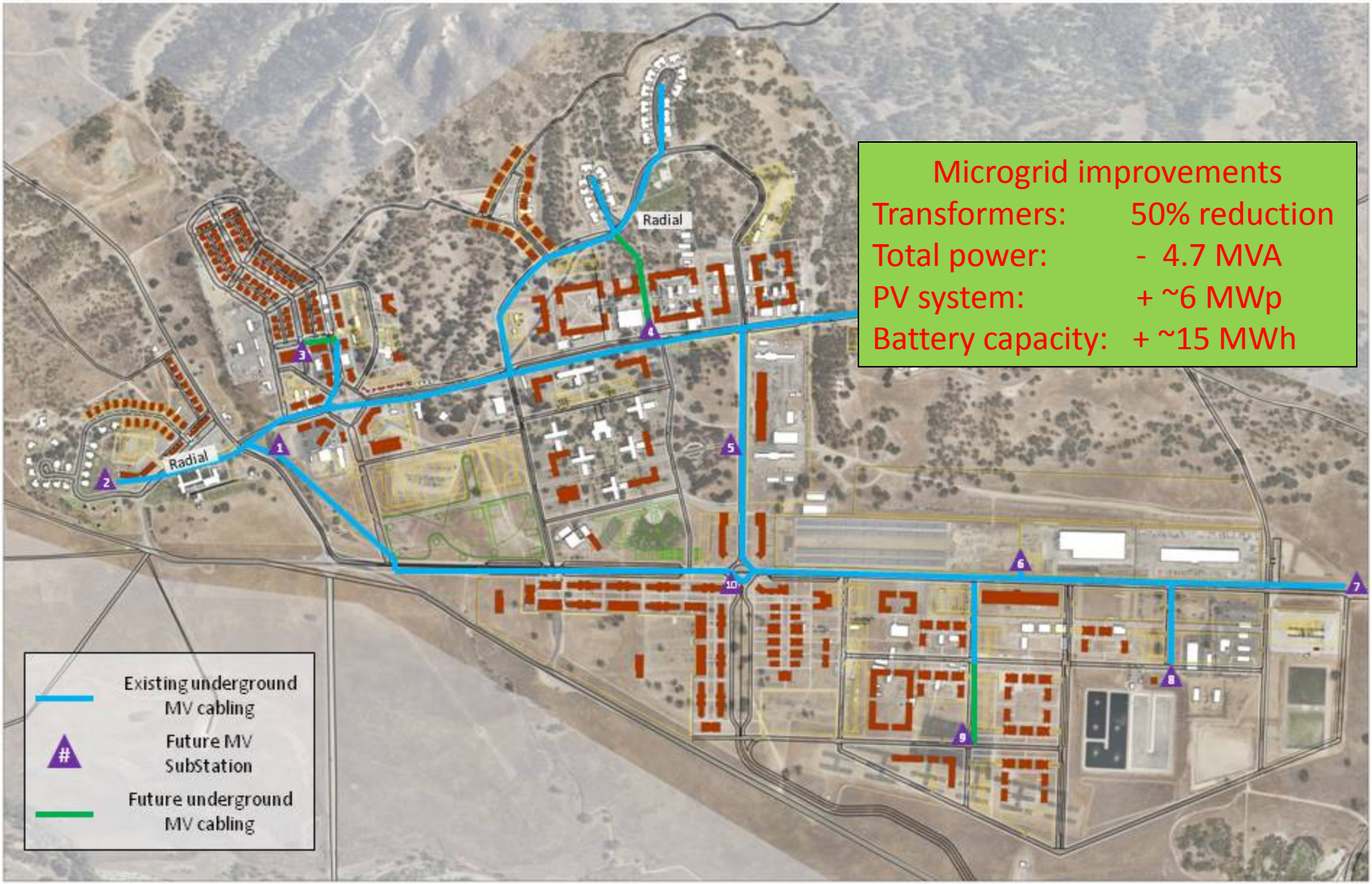



South Side



# US Army Garrison - Fort Hunter Liggett

## Micro Grid Concept Design



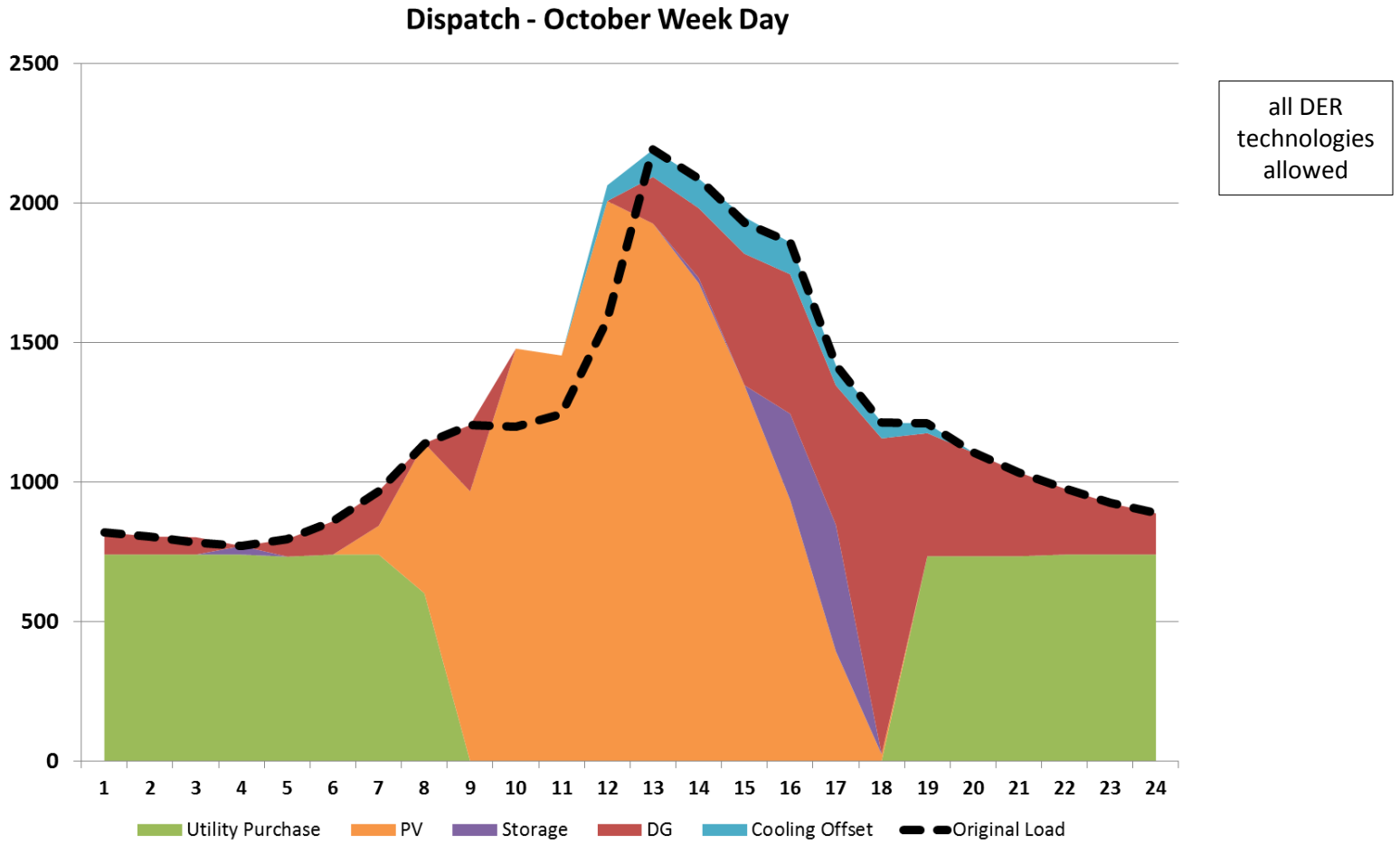

**Microgrid improvements**

| | |
|---|---|
| Transformers: | 50% reduction |
| Total power: | - 4.7 MVA |
| PV system: | + ~6 MWp |
| Battery capacity: | + ~15 MWh |

*Backup Slides*

# Microgrid Capabilities and Resiliency at Fort Hunter Liggett

## *Fort Hunter Liggett – Standard DER-CAM Assessment - no blackouts*




PV generation enables frequent voluntary islanding (no energy purchase during the day)