Energy Storage Management Systems (ESMS)

PRESENTED BY
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Outline

1. Energy Storage System (ESS) applications
2. Energy Storage Management System (ESMS) architecture and functions:
   1. Device Management System (DMS)
   2. Power Conversion System (PCS)
   3. Communication
3. ESMS Vendors and examples
4. Optimization and QuESt - Storage Evaluation Tool
Energy Storage Applications

- Power applications
  - Frequency regulation
  - Voltage support
  - Small signal stability
  - Renewable smoothing

- Energy applications
  - Energy arbitrage
  - Renewable energy time shift
  - Customer demand charge reduction
  - Transmission and distribution upgrade deferral
Energy Management System Overview

- EMS includes functionalities that maintain the optimal and safe operation of ESSs.
- EMS includes the customer, market, and utility interfaces.
- EMS dispatches each of the storage systems.
Energy Storage Management System

Image Credit: GTM Research
Device Management System (DMS)

- Basic functions of DMSs are often provided by storage device manufacturers, more advanced functions are usually provided by independent software/hardware vendors.

Measurement and State Estimation:
Measure (voltage, current, temp) and estimate the device states (SOC, SOH)

Diagnosis and Safety:
Ensure safety of the device through active and passive protection

Technology Specific Functions:
Flow battery electrolyte rebalancing or li-ion cell balancing
DMS Examples

Source: Texas Instrument

Source: Nuvation Energy
Power Conversion System (PCS)

PCS system includes two levels of control:

- Secondary control determines operating mode for each power converters, e.g., discharge, charge, standby.
- Primary control includes low level controllers that generate drive signals for power converters.
PCS Examples

Dynapower CPS-1000 - 1MVA Grid Inverter
For Frequency Regulation and Peak Reduction

ABB Energy Storage Inverter – ESI series (85 kVA to 315 kVA)

SMA Sunny Central Storage Inverter (up to 2750 kVA)
Modular Energy Storage Architecture (MESA): open, non-proprietary set of specifications and standards developed by industry consortium

- Each subsystem must be equipped with a communication interface to exchange data effectively
- Basic communication structures for an ESS can be found in current standards such as IEC61850-7-420 and MESA.
ESMS Vendor Landscape

- BMSs are often provided by battery manufacturers and software/solution vendors.

- The majority of ESMSs are provided by system integrators and power electronic vendors.
**ESMS Examples**

**Battery Energy Storage System (BESS)**

**Source:** ABB

**Project Name:** Ameren Testing Microgrid in IL

**Applications:** S&C deliver 500 kWh li-ion BESS to optimize the operation of a microgrid with 125 kW solar and 1MW natural gas generator

**ABB solution**

- Design, engineering, installation and testing of PowerStore Battery, transformer and diesel generator
- Microgrid Plus System for overall system management
- Based on transportable containerized solution

**Customer benefits**

- Manage peak demand - Active and reactive power support during high demand periods
- Transition into isolated Off-grid operation on command or in emergency cases without supply interruption
- Delay of power line investments

**About the project**

First Embedded Generation system with Battery Grid Energy Storage for distribution network support in Australia

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**PureWave® SMS**

**Storage Management System**

**Project Name:**

S&C delivered a 1-MW PureWave Storage Management System to help reduce the NOx emissions on Catalina Island, California.

**Developer/Operator:**

S&C Electric Company

**Suppliers:**

Southern California Edison

**Date:**

Operational Since July 2012

**Name of Project:**

S&C Electric Company

PureWave® Storage Management System Helps Reduce the NOx Emissions on Catalina Island, California

**Location:**

Catalina Island, California

**Source:** S&C and ESA
ESMS Examples

**BOSCH** Energy Management System

Three levels to save your energy.

- **Cloud:** Security, Collect, Analyze. The cloud is the heart of our Energy Management System. It provides data storage, cyber security, and usage optimization. The cloud continually collects data which is generated during system operation and allows detailed remote analysis and monitoring of the system.
- **Industrial PC:** Connected to the Cloud. The Industrial PC enables live access and control of the energy system by the customer. In addition, it provides a level of redundancy in case of microcontroller failure or loss of internet connection.
- **Microcontroller:** Energy Management in Real-Time. Real-time energy management of multiple energy assets and energy storage by a programmable logic controller (PLC) ensures safe and robust operations.

**Matrix Energy Management**

Source: Bosch

Source: EnSync
Optimization

\[
\begin{align*}
\text{maximize} & \quad \sum_{t=1}^{T} p_t^{DA} (q_t^D - q_t^R) \\
\text{subject to} & \quad S_{t+1} = \gamma_s S_t + \gamma_c q_t^R - q_t^D, \quad \forall t \\
& \quad S \leq S_t \leq \bar{S}, \quad \forall t \\
& \quad 0 \leq q_t^R \leq \bar{q}^R, \quad \forall t \\
& \quad 0 \leq q_t^D \leq \bar{q}^D, \quad \forall t
\end{align*}
\]
QuESt - Energy Storage Evaluation Tool

- Open source, Python-based energy storage analysis software application suite
- Developed as a graphical user interface (GUI) for the optimization modeling capabilities of Sandia’s energy storage analytics group
- Version 1.0 publicly released in September 2018
- Version 1.2 available on GitHub
  - github.com/rconcep/snl-quest or sandia.gov/ess
Why QuESt?

• For energy storage project stakeholders
  • Accessible and easy-to-use software tool for energy storage valuation and related applications

• For engineers/developers
  • Open source software project
  • GUI design, application design, Pyomo optimization modeling
  • Pyomo models and other optimization code can be adjusted to fit specific needs

• It’s free
  • Written in Python; no software licenses required

• Current application list
  • QuESt Data Manager – Manages acquisition of ISO market data, US utility rate data, commercial and residential load profiles, etc.
  • QuESt Valuation – Estimate potential revenue generated by energy storage systems providing multiple services in the electricity markets of ISOs/RTOs.
  • QuESt BTM - Estimate the cost savings for time-of-use/net energy metering customers using behind-the-meter energy storage systems.
Why QuESt?

- **For energy storage project stakeholders**
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General Workflow

- **Current application list**
  - **QuESt Data Manager** – Manages acquisition of ISO market data, US utility rate data, commercial and residential load profiles, etc.
  - **QuESt Valuation** – Estimate potential revenue generated by energy storage systems providing multiple services in the electricity markets of ISOs/RTOs.
  - **QuESt BTM** - Estimate the cost savings for time-of-use/net energy metering customers using behind-the-meter energy storage systems.

Decide what type of analysis to do.

- ISO/RTO value stacking => QuESt Valuation
- Behind-the-meter applications => QuESt BTM

Grab the appropriate data from QuESt Data Manager

- ISO/RTO market data
- Utility rate structure
- PV profile
- Load profile

Select the appropriate application from the first step.

- Set up the analysis and run it
- View and process results
Given an energy storage device, an electricity market with a certain payment structure, and market data, how would the device maximize the revenue generated and provide value?

\[
\max \sum_i \left( \lambda_i (q_i^d - \eta_c q_i^r) + q_i^{ru} (\lambda_i^{ru} + \delta_i^{ru} \lambda_i) + q_i^{rd} (\lambda_i^{rd} - \delta_i^{rd} \lambda_i) \right) e^{-R_i}
\]

subject to:

\[
s_{i+1} = \eta_s s_i + \eta_c q_i^r - q_i^d + \eta_c \delta_i^{rd} q_i^{rd} - \delta_i^{ru} q_i^{ru}
\]

\[0 \leq s_i \leq \tilde{S}\]

\[q_i^d + q_i^r + q_i^{ru} + q_i^{rd} \leq \tilde{Q}\]

- Other constraints, such as requiring the final SoC to equal the initial SoC or reserving energy capacity for resiliency applications can be set.
- Varies based on market and available value streams
QuESt Evaluation

Select a market area to place the energy storage device in.

Different market areas can have different market structures, resulting in various opportunities for generating revenue.

<table>
<thead>
<tr>
<th>ERCOT</th>
<th>PIM</th>
<th>MISO</th>
</tr>
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<td>NYISO</td>
<td>ISONE</td>
<td>SPP</td>
</tr>
<tr>
<td>CAISO</td>
<td></td>
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</tbody>
</table>

Describe the type of energy storage device to be used.

Energy storage devices come in many forms and technologies. In this application, they are mainly modeled according to their power and energy ratings. Select an energy storage device template and/or customize your own.

- Li-ion Battery
- Advanced Lead-acid Battery
- Flywheel
- Vanadium Redox Flow Battery

- Li-ion Battery
  - Model: after the Notrees Battery Storage Project in western TX.
  - Self-discharge efficiency (W/1h): 100.0%
  - Round trip efficiency (%): 90.0%
  - Energy capacity (MWh): 24.0
  - Power rating (MW): 36.0

Here’s how the device generated revenue each month.

Revenue was generated based on participation in the selected revenue streams. The gross revenue generated over the evaluation period was **$3,064,793.94**. The gross revenue from arbitrage was **$526,420.06**, an overall deficit. This implies participation in arbitrage was solely for the purpose of having capacity to offer regulation up services.

Reports

- Revenue (by month)
- Revenue (by stream)
- Participation (total)
- Participation (by month)
QuESt Behind-the-meter

A collection of applications for behind-the-meter energy storage. The first application estimates cost savings for time-of-use and net energy metering customers.

- Incorporate specific utility rate structures (energy TOU schedule and rates, etc.)
- Use location-specific simulated load and photovoltaic power data

Here's the total bill with and without energy storage for each month.

The total bill is the sum of demand charges, energy charges, and net metering charges or credits. It looks like the ESS was able to decrease the total charges over the year by $1,762.19.
QuESt Behind-the-meter

Specify the energy storage system parameters.

- **Energy capacity**: The maximum amount of energy that the ESS can store.
  - 80 kWh

- **Power rating**: The maximum rate at which the ESS can charge or discharge energy.
  - 20 kW

- **Transformer rating**: The maximum amount of power that can be exchanged.
  - 1000000 kW

- **Self-discharge efficiency**: The percentage of stored energy that the ESS retains on an hourly basis.
  - 100 %

- **Round trip efficiency**: The percentage of energy charged that the ESS actually retains.
  - 85 %

- **Minimum state of charge**: The minimum ESS state of charge as a percentage of energy capacity.
  - 85 %

- **Maximum state of charge**: The maximum ESS state of charge as a percentage of energy capacity.
  - 100 %

- **Initial state of charge**: The percentage of energy capacity that the ESS begins with.
  - 50 %

Here's the total bill with and without energy storage for each month.

The total bill is the sum of demand charges, energy charges, and net metering charges or credits. It looks like the ESS was able to **decrease** the total charges over the year by $3,712.70.

- Without ESS: $3,172
- With ESS: $3,376

Here are the peak demand values each month.

The peak demand value each month is used to compute flat demand charges, if applicable. For this rate structure, there were no flat demand charges.

- Without ESS
- With ESS

Reports

- Total bill
- Total bill comparison
- Demand charge comparison
- Energy charge comparison
- NEM comparison
- Peak demand comparison

Generate report
The code is hosted on GitHub
- github.com/rconcep/snl-quest

General installation requirements:
- Windows/OS X/Linux
- Python 3.6+
- Kivy 1.10.1
- (Linear program) solver compatible with Pyomo
  - GLPK
  - CBC
  - Gurobi

For Windows 10, we have an experimental executable version of QuESt
- Comes with its own Python environment fully configured
- Just run the .exe
- Currently still requires a solver for Pyomo
- Working on an .app/.dmg for OS X…
References

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