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에너지 최적화를 위한 에너지 관리 시스템(EMS)

강효석
Motivation

Renewables

Uncertainty

Distributed Generation

Data

Regulatory Oversight

- CEMS
- HEMS
- FEMS
- BEMS
Motivation

As-is
- Static policies
  - Off-line data
  - Manual operation

To-be
- Dynamic policies
  - Real-time data
  - Automated operation

Smart Energy Management Systems (EMS) are a MUST in a smart energy society.
Traditional EMS

25% cost reduction

Smart EMS
Develop Smart EMS

Big Data

Data Analytics
Prediction Model
Forecast data
Optimization
Control Algorithm

System Simulation

Deploy

Deployed
Community EMS

**CEMS – community with variable loads**

**PV Panels:**
- MPPT Control
- Power electronics

**Decision Logic:**
- Store/draw power
- Use external grid
- Optimize energy

**Battery System:**
- Charge controls
- Discharge controls
- Power electronics
Community EMS

Electrical Grid

Variable Load

Fixed Load

Solar Array

ESS System
Community EMS

Variable Load

Solar Array

24hr

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EMS Logic

Heuristic EMS

Traditional EMS

Smart EMS

Linear Programming Optimization Routine

Smart EMS

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EMS Logic

Heuristic EMS

Smart EMS

Cost [\$/kWh]

Time

Load Power Profile

Grid Power Consumption

Energy Storage Consumption

Grid to Storage

Storage to Grid

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Simulation Results

Smart EMS
What do you need to build a smart EMS?

- Integrated development environment
  - Data analysis
  - Predictive modeling
  - Optimization
  - Control
  - System Design

- Virtual prototyping

- Deployment options
  - Deploy to embedded systems
  - Deploy to enterprise systems
EMS Development Workflow

Access Data  Analyze Data  Develop  Deploy
EMS Development Workflow

**Access Data**

**Analyze Data**

**Develop**

**Deploy**

**Engineering Data**
- Electric load: user's electrical load, cooling load, ...
- Sensor data: irradiance, wind speed, temperature, ...

**Business Data**
- Market information: electricity prices, gas prices, equipment costs, interest rates, ...

Need ways to access both business and engineering data
EMS Development Workflow

- **Access Data**
- **Analyze Data**
- **Develop**
- **Deploy**

**Data Preprocessing Messy Data**
- Missing data, outliers, sampling, …
- Filtering and smoothing, resampling, …
- Join, stack, group, discretize

**Need a powerful technical computing environment**
Access and Analyze Data

- Point and click tools to access variety of data sources
- High-performance environment for big data

- Built-in algorithms for data preprocessing including sensor, image, audio, video and other real-time data
Access Data

![Image of a spreadsheet using MATLAB]

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Make it easy to handle Data for Data Analytics

- **For:**
  - Mixed-type tabular data
  - Include metadata
  - Time-stamped tabular data

- **Provides:**
  - Flexible indexing
  - Data organization
    - joins, stack/unstack, etc.
  - Indexing by time, time range, or within a tolerance around a time
  - Retiming to create a constant sample rate

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Access Data

Access all data using a tall array

% To use a tall array, we start by creating a datastore that points to
% where the data lives. This could be large text files, large collections
% of small files, or pageable databases (requires Database Toolbox).

dataFolder = '.\Data\';

ds = datastore(dataFolder);

...
Tall Arrays

- Data is in one or more files
- Typically tabular data
- Files stacked vertically
- Data doesn’t fit into memory (even cluster memory)

- Create tall table from datastore

```matlab
ds = datastore('*.csv')
tt = tall(ds)
```
Tall Arrays

- With Parallel Computing Toolbox, process several pieces at once.
# Enterprise Data Access

## Data

<table>
<thead>
<tr>
<th>Databases</th>
<th>Cloud Storage</th>
<th>IoT &amp; Big Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassandra</td>
<td>Azure Blob</td>
<td>HORTONWORKS</td>
</tr>
<tr>
<td>SQL Server</td>
<td>Azure SQL</td>
<td>Cloudera</td>
</tr>
<tr>
<td>MongoDB</td>
<td>Amazon S3</td>
<td></td>
</tr>
</tbody>
</table>

## Analytics

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Analyze Data

- Pre-processing
  - Data Cleaning
    - Missing Data
    - Merging Data
    - Outliners and Smoothing
    - Filtering
  - Normalization/Calibration
  - Aggregation/Resampling
  - Data Reduction/Transformation

- Post-processing
  - Feature Extraction
  - Grouping
  - Regression
  - Classification

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EMS Development Workflow

- Predictive Models
  - Energy demand
  - Electricity price
  - Weather
  - Consumer behavior

Need quick iteration of various predictive models
EMS Development Workflow

- **Objectives on cost, comfort, reliability**
- **Constraints to meet demand, respect equipment and system limitations**

Need reliable optimization solvers
EMS Development Workflow

**System Simulation Models**
- Plan strategies of system function and performance on desktop
- Simulate physical system performance with high fidelity
  - Analyze edge conditions
- Simulate multiple scenarios quickly with low fidelity
  - Perform statistical analysis on results

**Need virtual prototyping environment**
Prediction Example: Energy Demand

- Make prediction model using the pattern of energy demand with the data of the grid → Regression
- Find the important variables for the prediction of energy demand
  - Important variables:
    - Customer behavior
    - Temperature
    - Price
    - Illumination
    - Hour, holiday, month
    - …
Evaluate all Regression Models
Finding the best prediction model

- Train all models using training data and compare accuracy of each one
  - Trainings can run in parallel
- Multiple methods to assess accuracy
Optimization: Community EMS with PV and Battery
Optimization: Community EMS with PV and Battery
Optimization: Community EMS with PV and Battery

minimize \( \sum_{t=1}^{N} \delta c_t G_t - wE_N + \sum_{t=1}^{N-1} g_t \)

subject to

- \( E_1 = E_{\text{initial}} \)
- \( E_{t+1} = E_t - \delta B_t \)
- \( s_t + G_t + B_t = d_t \)
- \( G_{t+1} - G_t \leq g_t \)
- \( G_t - G_{t+1} \leq g_t \)

\( G_t \) Power from grid

\( l_B \leq B_t \leq u_B \) Power from battery

\( l_E \leq E_t \leq u_E \) Stored energy

\( g_t \) Change in power from grid

\[% - Smooth period-to-period changes with a penalty\]
prob.ObjectiveSense = 'minimize';
prob.Objective = dt*Cost*PgridV - FinalWeight*EbatTV(N) + sum(PgridDelta);
### Solving: Problem Types and Algorithms

<table>
<thead>
<tr>
<th>Category</th>
<th>Algorithms</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Linear programming</strong></td>
<td>- Simplex and interior point</td>
</tr>
<tr>
<td><strong>Mixed-integer linear programming</strong></td>
<td>- Branch and cut</td>
</tr>
<tr>
<td><strong>Quadratic programming</strong></td>
<td>- Interior point and trust region</td>
</tr>
<tr>
<td><strong>Least-squares and nonlinear equations</strong></td>
<td>- Interior point, trust region, Levenberg-Marquardt</td>
</tr>
<tr>
<td><strong>Multiobjective optimization</strong></td>
<td>- Weighted and goal-attainment</td>
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<td></td>
<td>- <strong>Genetic algorithm</strong></td>
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<tr>
<td></td>
<td>- <strong>Pattern (direct) search</strong></td>
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<tr>
<td><strong>Nonlinear optimization</strong></td>
<td>- Interior point</td>
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<td>- SQP</td>
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<td>- Trust region</td>
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<td></td>
<td>- Nelder-Mead simplex</td>
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<td></td>
<td>- <strong>MultiStart &amp; GlobalSearch</strong></td>
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<td>- <strong>Simulated annealing</strong></td>
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<td></td>
<td>- <strong>Particle swarm</strong></td>
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<tr>
<td></td>
<td>- <strong>Surrogate optimization</strong></td>
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<tr>
<td><strong>Mixed-integer nonlinear optimization</strong></td>
<td>- Genetic algorithm</td>
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System Simulation – Model Configuration
- Community EMS

Simulation platform
MATLAB, Simulink

1D physical modeling
Simscape Electrical™

Speed-up of parameter study
Parallel Computing Toolbox™

Optimization solver
Optimization Toolbox™
System Simulation – Plant Modeling

- Advantage of Simscape Electrical
  - Easy to build a circuit model
  - Fidelity change for each component
  - Integration with data
  - High scalability and reusability

High Fidelity for Accuracy

Low Fidelity for Simulation Speed

Solar Array

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System Simulation – Smart EMS

- Optimize electricity cost every few hours
  - Linear programming solver in Optimization Toolbox
  - Input
    - Battery stored energy
    - Control Parameters
    - Predicted data
  - Output
    - Charging/Discharging command

MATLAB function block

MATLAB script

predicted data
- Consumed power
- Buying/Selling electricity price

Charging/Discharging command to battery

Battery stored energy

Control Parameters

Forecast Algorithms
- CostForecast
- Sliding Cost Values
- PpvForecast
- Sliding PV Power
- PloadForecast
  - Sliding Load Power

Optimization-based Energy Management

Optimal Author

BattEnergy
Nominal Charge
OptTime
Time between optimizations

Batt
Opt
Ppv
Load
PpvForecast
Sliding PV Power
PloadForecast
Sliding Load Power

Eloss
Echg
Ebat
SOC

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Policy Comparison - Cloudy Day

Heuristic

Optimized

Comparison

14% lower cost with optimization
Community EMS

CEMS – community with variable loads

PV Panels:
- MPPT Control
- Power electronics

Decision Logic:
- Store/draw power
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Battery System:
- Charge controls
- Discharge controls
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EMS Development Workflow

Deployment
- System integration, system test
- Continuously monitor performance
  - Monitor for predictive maintenance
  - Use models as digital twins
  - Analyze against system objectives

Need to consider integration to both embedded systems and enterprise IT Workflows
Integrate Analytics with Systems

MATLAB

Embedded Hardware
C, C++, HDL, PLC

Enterprise Systems
Standalone Application, Excel Add-in, Hadoop/Spark, C/C++, Java, Python, .NET, MATLAB Production Server

MATLAB Runtime

For k=1:max
x = fft(dat)
y = 20*log1

For k=1:max
x = fft(dat)
y = 20*log1

...
Deployment Workflow on Embedded Systems

Design
- Desktop Simulation
- C Code Generation
- PLC Code Generation

Implement
- Real-time Interface
- PLC Development Environment

Test
- Equipment Simulation
- Bus
- Industrial Controller

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Click the ‘Package’ button and wait for the compiler to generate the deployable archive.

Copy .ctf file into the auto_deploy folder or use web dashboard.

Deployment Workflow on Cloud and Business Systems
Integration with Enterprise IT

Data

- Databases
  - Cassandra
  - MongoDB
  - SQL Server

- Cloud Storage
  - Azure Blob
  - Amazon S3

- IoT & Big Data
  - Apache Kafka
  - Azure IoT Hub
  - Cloudera

Analytics

- MATLAB
  - MATLAB Production Server
  - MATLAB Parallel Server

Business System

- Visualization
  - Tableau
  - Qlik
  - Microsoft Power BI

- Web
  - Microsoft IIS
  - WebSphere
  - Apache Tomcat

- Custom App

Platform

- Public Cloud
  - Microsoft Azure
  - Amazon Web Services
  - Rackspace
  - OpenStack
  - VMware

- Private Cloud

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EMS Development Workflow

- **Access Data**
- **Analyze Data**
- **Develop**
- **Deploy**

Data processing
Prediction
Optimization
Integration
System simulation
BuildingIQ Develops Proactive Algorithms for HVAC Energy Optimization in Large-Scale Buildings

Challenge
Develop a real-time system to minimize HVAC energy costs in large-scale commercial buildings via proactive, predictive optimization

Solution
Use MATLAB to analyze and visualize big data sets, implement advanced optimization algorithms, and run the algorithms in a production cloud environment

Results
- Gigabytes of data analyzed and visualized
- Algorithm development speed increased tenfold
- Best algorithmic approaches quickly identified

“MATLAB has helped accelerate our R&D and deployment with its robust numerical algorithms, extensive visualization and analytics tools, reliable optimization routines, support for object-oriented programming, and ability to run in the cloud with our production Java applications.”
- Borislav Savkovic, Building IQ

Large-scale commercial buildings can reduce energy costs by 10–25% with BuildingIQ’s energy optimization system.
Shanghai Electric Builds and Deploys Cost-Saving Enterprise Software for Planning and Designing Distributed Energy Systems

Challenge
Develop web-accessible software for planning and designing distributed energy systems

Solution
Use MATLAB to develop algorithms that compute investment return based on models of energy production subsystems, loads, and grids, and then use MATLAB Production Server to deploy the algorithms in a production IT system

Results
- Delivery time reduced by six months
- 2 million Chinese yuan saved on a single project
- Updates deployed immediately and without IT assistance

"My team’s expertise is in energy modeling or algorithm development, not in deploying software into production. MATLAB saved us months of development time on the models and algorithms, and then made it easy to deploy them as part of a stable, reliable web application without recoding."

- Yunjiao Gu, Shanghai Electric
MATLAB & Simulink help you build a smart EMS

- Integrated development environment
  - Data analytics
  - Predictive modeling
  - Optimization
  - Control
  - System Design

- Virtual prototyping

- Deployment options
  - Deploy to embedded systems
  - Deploy to enterprise systems
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데모 부스와 상담부스로 질문 하시기 바랍니다.

감사합니다
Learn More

On the web

- Microgrid System Development and Analysis - video series
- Data Analytics with MATLAB - webinar
- Linear and Mixed-Integer Linear Programming in MATLAB - webinar
Products

In the microgrid demo
- MATLAB
- Simulink
- Simscape
- Simscape Electrical
- Stateflow
- Optimization Toolbox

Additional products for EMS
- Statistics & Machine Learning Toolbox
- Model Predictive Control Toolbox
- Signal Processing Toolbox
- Control System Toolbox
- MATLAB Compiler
- Embedded Coder
- Simulink Test
- MATLAB Production Server
- MATLAB Parallel Server