Focus Area: Energy/Power Management Systems

Grid integration, micro grids, power on demand, high efficiency conversion, high density power electronics, power converter for harsh environments, sensor networks for power systems, control and optimization of power circuits/electronics fault management and security in power systems.

Core faculty: Juan Rivas-Davila, Stephen Boyd, Sanjay Lall, Ram Rajagopal, David Tse
Affiliated faculty: Dimitry Gorinevsky, Marco Pavone, Daniel C. O'Neill
Smart Grid: Stochastic Optimization for Smart Grid
Big Data analytics, non-parametric model, quantile regression, ADMM optimization

Historical Data: Power Load, Price
Quantile Regression Fit

Today’s Load and Price Data
Stochastic Optimization

Non-Parametric Stochastic Model
\[
\begin{align*}
& \mathbb{P}(y_i \leq y | Z_i) = q \\
& y(q) = Z_i \beta(q) + \alpha(q) \\
& p(y_P | Z_i) = dq/dy_P(q) \\
& p(y_P | y_P, Z_i) = dr/dr_P(r, q)
\end{align*}
\]

Optimized Day-ahead Order
Improvement: $2.4 million/year

Dimitry Gorinevsky and Stephen Boyd
Smart Grid: Data-driven Risk Analytics for Energy and Climate


Dimitry Gorinevsky, with Stephen Chu (Physics)
Web platform and open source software for
- Consumer response modeling and prediction
- Load scheduling and forecasting
- Rate and real-time pricing design
- Targeting storage, solar, DR and other technologies
- Fault isolation and service restoration

Contact: Chin Woo Tan (tancw@stanford.edu)  PI: Ram Rajagopal
Smart Grid: Line Sensor for Distribution Networks

Very low cost, high accuracy power sensing for distribution systems:

- Self-powered, voltage and current sensor using a novel active measurement technique.
- Applications: outage and topology detection, voltage control, PMU.
**Objective:** to generate models and methods for the system-level control of robotic transportation networks wherein shared, self-driving, and electric vehicles provide mobility and connect to the smart grid for recharging (Figure 1).

**Current work:**
- Queueing-theoretical models of robotic transportation networks (RTN).
- Dynamic routing algorithms for RTN.
- Optimization of battery recharging.
- Demo involving autonomous NAVIA shuttles (Figure 2). Collaboration with SLAC and US Army ARIBO program.

Contact: Marco Pavone
**Smart Grid: Work based on power Data**

- **Demand Response (DR)**
  - Energy provider
  - Policy
  - Energy consumers reduce electricity use at time of market high price.

- DR policy requires a prediction of consumer energy consumption patterns.
- There exists a wide variety of load shapes; Data can contain a million of load shapes.

- **Approach**: Cluster load shapes into K classes, using Dynamic Time Warping (DTW).

- **Model of Consumer**: Daily activities generates power consumption patterns. Timing varies within bound.
  - **Example**: S1 and S2 are Ben’s load shapes. He showers an hour late on day 2 so the corresponding power usage shifts to the right. We want to group S1 and S2 together.

**Previous work**: Clustering load shapes based on L2 dissimilarity penalizes mismatch across the horizon. Sanjay Lall, Nicky Teeraratkul

**Our approach**: Clustering load shapes based DTW dissimilarity produces optimal alignment between two series, allowing them to match.
• **Implementation**: Calculate DTW distance between load shape vectors using dynamic program with a set of allowed search path, then use DTW distance matrix in divisive hierarchical clustering.

• **Result**: Compared to using L2, clustering using DTW,
  – We get half a number of clusters.
  – Each cluster is more compact.
  – Household is represented by a fewer clusters -> **Easier to continue the prediction problem for DR.**

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![Diagram illustrating load shapes and clustering methods](image_url)

- **DTW** groups all load shapes into a single cluster.
- **L2** separates load shapes into 2 clusters.

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With a fixed number of clusters, DTW achieves smaller WC, which indicates more compactness.
Data Centers: Distributed Control of Microgrids

Designing algorithms and hardware for plug and play control of microgrids:

- Stable control of networks of inverters and DC/DC converters.
- Constant power load modeling.
- Distributed asynchronous AC and DC OPF solving.
- Low-cost embedded controller supporting storage, solar, fuel cells for power optimization and local voltage control in Data Centers, Buildings, Campus.

Contact: Chin Woo Tan (tancw@stanford.edu)    PI: Ram Rajagopal, Stephen Boyd

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Power Electronics: Aircore magnetics

- Air-core components not subject to saturation or Curie temperature limitations
- Toroidal are an improvements over solenoids as the magnetic field is constrained to the torus
  - Lower stray fields → Lower EMI issues
- PCB toroids have better copper coverage and lower loss and very repeatable
- Better air-core passives are possible with new fabrication techniques

Prof. Juan Rivas, Wei Liang, Luke Raymond
3D Printing can overcome limitations of PCBs and wire-wound inductors
- Overhangs, curved surfaces possible
- Design flexibility to optimize cross section
  - Higher quality factor
  - FEM tools allow 3D printing all passives in power converters
Power Electronics: 3D Printed Passive Components

Fig.: toroid inductor with a round cross section. OD=29mm, ID=11mm, N=20.
Power Electronics: Performance evaluation of diodes under high voltage and high slew rate

- SiC diodes at 10's of MHz and high dv/dt present losses that can limit application at high voltages.

- Understanding and accurate modeling may lead to higher power density supplies for x-rays, satellites.

Prof. Juan Rivas, Luke Raymond, Wei Liang