Smart Systems in Research and in the Classroom

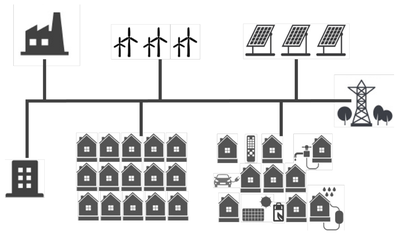
Kody M. Powell
Department of Chemical Engineering
University of Utah

Research and Professor Overview

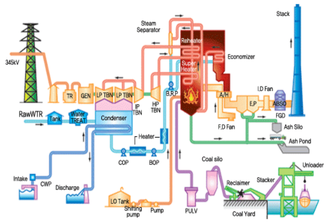
Background

- **Assistant Professor at the University of Utah (2016-Present)**
  - Energy systems research
  - Optimization of smart grid systems with energy storage
  - Design and simulation of solar thermal hybrid systems
  - Director of DOE-funded Industrial Assessment Center
- **Process control Engineer and Real-time Optimization Engineer at ExxonMobil Research and Engineering (2013-2016)**
  - Specialized in combined heat and power systems
- **Ph.D. from University of Texas at Austin**
  - Dynamic optimization of energy systems with storage
- **B.S. from University of Utah**

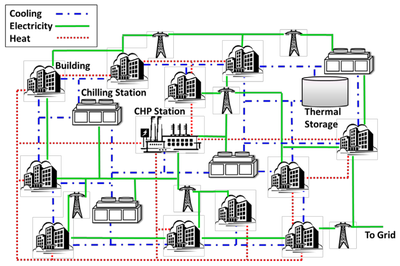
Smart Grid: Leveraging Distributed Storage for Incorporation of Renewables



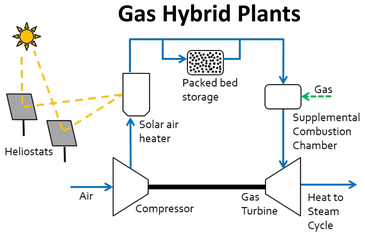
Artificial Intelligence to Improve Emissions of Thermal Power Plants



Energy Optimization of District and Industrial Energy Systems

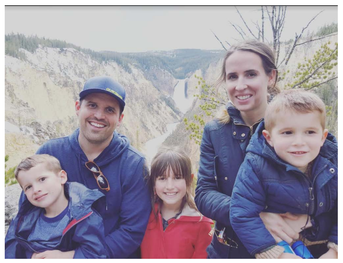


Flexible Solar Thermal and Gas Hybrid Plants



Energy Efficiency in Manufacturing and Industrial Energy Management

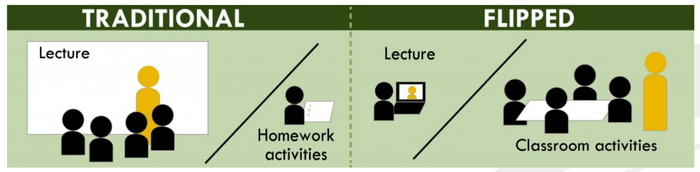
INTERMOUNTAIN INDUSTRIAL ASSESSMENT CENTER



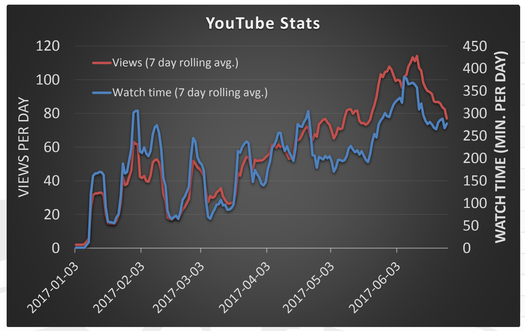
Smart Systems: A New Class with a Unique Format

The Basic Idea

- Very **interactive** class called “Smart Systems”
- **Flipped** Classroom
- Lectures on **YouTube**
- **Mini-projects** done in Computer Lab
- Students learn by **doing** and **seeing** the results



Analytics from Online Course Content



Geography	Watch time (minutes)	Views
United States	14,175 (40%)	2,869 (29%)
India	3,317 (9.5%)	1,594 (16%)
Germany	1,740 (5.0%)	425 (4.2%)
United Kingdom	1,301 (3.7%)	419 (4.2%)
Canada	1,065 (3.0%)	293 (2.9%)
Malaysia	927 (2.6%)	255 (2.5%)
Netherlands	751 (2.1%)	183 (1.8%)
Brazil	740 (2.1%)	194 (1.9%)
Australia	545 (1.6%)	174 (1.7%)
Indonesia	444 (1.3%)	164 (1.6%)
South Korea	439 (1.3%)	135 (1.3%)
Italy	411 (1.2%)	108 (1.1%)
Turkey	397 (1.1%)	167 (1.7%)

TONS of data from YouTube!!

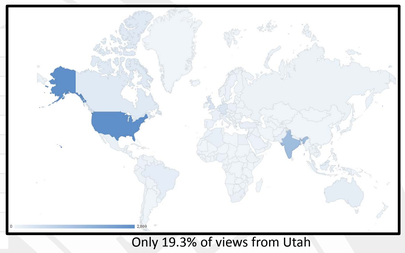
Modular Content

Every **module** has accompanying YouTube Videos and a mini project

- Students **build their own plant** in the first module and then apply various **“smart” automation schemes** to their plant
- Topics: **Breadth** (not so much depth)
  - Dynamic simulation of CSTR in MATLAB/Simulink
  - Crash course in PID controls (very applied approach)
  - Coding smart logic into a control scheme
  - Empirical modeling using multiple least squares
  - Quadratic programming
  - Nonlinear programming
  - Real-time optimization
  - Machine Learning with Neural Networks

Assignment 3: Developing a batch controller for product tanks	How to program an on/off controller and use custom logic to implement hysteresis	https://www.youtube.com/watch?v=CrRq4GKENr8	2/13/17
Assignment 4: Empirical Modeling using Multiple Least Squares	Mathematical derivation of multiple least squares	https://www.youtube.com/watch?v=eLwLFdyBnv4&t=318s	2/27/17
	Application of multiple least squares in Matlab	https://www.youtube.com/watch?v=-Hh50-KGvlY&t=88s	2/27/17
	How to export data from Simulink to Matlab	https://www.youtube.com/watch?v=mCJNuHSPdoU	2/27/17
	Mathematical derivation of least squares	https://isites.harvard.edu/fs/docs/icb.topic515975.files/OLSDerivation.pdf	Not required, but useful information
Assignment 5: Quadratic Programming (QP) and Real-Time Optimization (RTO)	Introduction to Optimization	https://www.youtube.com/watch?v=1UpGIG_P_w	3/20/17
	Overview of Quadratic Programming	https://www.youtube.com/watch?v=GZbr9647X8s&t=190s	3/20/17
	How to solve a Quadratic Program in Matlab	https://www.youtube.com/watch?v=2LhN8DwIa_c	3/20/17
	Overview of Real-Time Optimization	Placeholder for next year	
Assignment 6: Nonlinear Programming (NLP) and RTO	Overview of Nonlinear Programming	https://www.youtube.com/watch?v=K7eHfL4dYN8&t=58s	4/5/17
	Application of Nonlinear Programming in Matlab	https://www.youtube.com/watch?v=qTJDNXRfccc&t=932s	4/5/17

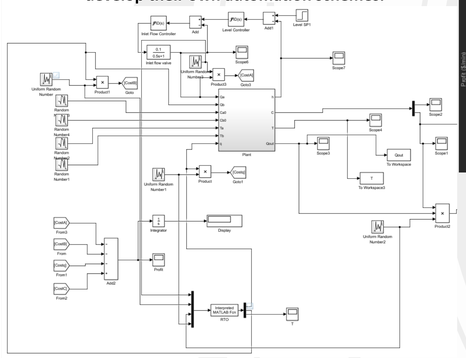
Video	Watch time (minutes)	Views
Overview of Quadratic Programming (QP)	5,368 (15%)	1,316 (13%)
Using Artificial Neural Networks to Model Com...	5,072 (15%)	1,451 (14%)
Controller tuning and controller saturation/win...	2,680 (7.6%)	783 (7.8%)
Introduction to override control	2,022 (5.8%)	485 (4.8%)
Implementing a simple, dynamic gravity-draine...	1,861 (5.3%)	361 (3.6%)
How to program an on/off controller and use c...	1,700 (4.8%)	466 (4.6%)
Dynamic Simulation of CSTR in Simulink	1,684 (4.8%)	736 (7.3%)
Introduction to cascade control	1,572 (4.5%)	468 (4.6%)
Introduction to Machine Learning: The Artificial...	1,566 (4.5%)	171 (1.7%)
Application of Nonlinear Programming in Matlab	1,514 (4.3%)	412 (4.1%)



Only 19.3% of views from Utah

Student Experience

Students build their own plant and develop their own automation schemes.

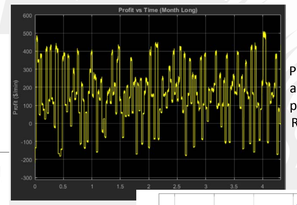


Students see tangible benefits.

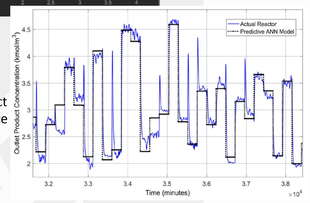
Method	Month-long simulation Profit
Base Case	$6,637,000
QP RTO	$7,187,000
NLP RTO	$8,280,000

From Module 6: Profit for one month comparing base operation vs. different RTO methods

Students analyze results.



From Module 5: Profit vs. Time when applying a quadratic programming-based Real-time optimizer



From Module 7: Using machine learning to predict plant performance

Student Feedback

- “The **hands-on style** of the class really **facilitated my learning** and helped me to more fully understand how these things can be used in the **real world**, and helped me learn it in such a way that I could do it again later.”
- “I learned more about control in this class than the actual control class I took last year.”
- “I **really liked the online videos for learning** and then the **class time to work on assignments**.”
- “This was an exceptionally great course in which everything that was learned was both **practical and useful**. The material was also very well communicated and taught. I would highly recommend this course to others.”
- “The video lectures were great and easy to follow, the **flipped format was great**. I also really liked how **each assignment built upon the previous ones** and the system grew more complex throughout the course.”
- “This class was taught in a flipped format, which I thought was great. Each new assignment was a **continuation of the previous assignment**, which was great for learning plant control.”
- “The format of watching videos at home and doing work in class is great. **Recorded lectures are awesome for student learning** because we can **learn and relearn the material at our own pace**.”
- “It was actually **related to industry** and **helped bridge learning school and work**.”
- “I learned so much in this class. I feel the material covered was extremely useful and the **class layout was perfect** for the subject matter.”

Key Takeaways

- **Don’t be a perfectionist on the videos**
- **Only slightly more effort than preparing traditional lectures**
- **One-on-one interactions were invaluable**
- **Big time investment in the computer lab**
- **Very active instructor needed for troubleshooting and explaining**

Improvements to Make

- **More complex assignments**
- **Condense timeline for more modules**
- **Open-ended projects**
- **Differentiate student grades**
- **Better time management between slow and fast students**
  - **Extra objectives for fast students**