Course Project Guide

This guide provides instructions for your class projects. Please read the guide carefully, and follow the instructions for submission. We sincerely hope it helps you deliver a thoughtful, high-quality project.

Timeline

All deliverables must be submitted through the appropriate "Assignment" on bCourses by Friday@5pm PT.

Deliverable	**Date (Due F@5p)**
Project Declaration	Jan. 29
Project Proposal	Feb 26
Progress Report	Mar 18
Poster/Project Board Presentation	Week of May 2
Final Report	May 6
Self/Team Evaluation	May 6

Contents

1 Introduction

1.1 Synopsis

The Energy Systems and Control course projects intend to provide students with a "hands-on" opportunity to apply systems and control concepts to the energy application of their choice. As a result, excellent projects will identify an energy system of interest, and a particular systems and control tool. Creativity is highly valued in outlining ideas. Moreover, students are encouraged to select topics that synergistically leverage their own research, other course projects, or industry experiences.

1.2 Requirements

Teams must consist of 3-4 students. Two-student teams are permissible, with consent of the instructor. A one-person team is NOT permissible. The projects must contain a specific energy system application. Moreover, they MUST apply one of the tools discussed in class, e.g. modeling, parameter identification, state estimation, control, or optimization. Most importantly, the project scope must be commensurate with a 15 week semester course.

2 Deliverables

2.1 Declaration [1 pts]

Submit the following three pieces of information:

1. Project Team: Names & e-mails of each team (3-4 per team). A two-member team is possible, with an e-mail petition to Prof. Moura.
2. One-sentence description of project topic: A super-brief preliminary topic. You are *not bound* to this topic, and are free to propose something different when the actual project proposal is due. The idea is, simply, to get your team assembled and brainstorming ideas ASAP.
3. Systems-and-Control Tool: Which systems-and-control tool(s) will your project apply? You must pick at least one among: (a) CH1 - Mathematical modeling, (b) CH2 - Model Identification, (c) CH3 - State Estimation, (d) CH4 - Optimization, (e) CH5 - Optimal Control. See the course notes for a flavor of each topic.

Selected project reports from previous years can be found here: http://ecal.berkeley.edu/ce295.html

2.2 Proposal [5 pts]

- Page limits: 2 page with figures and references
- Submitted on bCourses under "Project Proposal" Assignment

The format must follow the outline below:

(I) **[Title & Team Member Names]**

(II) **[Abstract]** Summarize the project in 200 words or less.

(III) **[Introduction]**

  (a) **[Motivation & Background]** This section provides answers to the following questions. Why is this topic interesting and important to study? What are the challenges associated with managing this particular energy system? Teams may optionally indicate how their previous experiences uniquely position themselves to study this topic. Teams may also indicate how this topic synergistically combines with their own research, other classes, etc.

  (b) **[Focus of this Study]** Provide a precise statement of this study's focus, contextualized within the broader energy issues and related literature.

(IV) **[Relevant Literature]** List the key references that provide the relevant background for your project. These references should be included in an enumerated list at the end of the document. These references can include published articles, textbooks, etc.

(V) **[Statement of Work]** Everything else is preamble. This is the meat of your proposal! Provide a table, or enumerated lists of tasks you plan to execute. Of course, this is only a projected work plan, as you may change course as the project unfolds. List what each team member will be responsible for.

(VI) **[Summary]** Summarize the project's aim and results. A reader should understand the main ideas by only reading the abstract and summary.

2.3 Progress Report [5 pts]

- Page limits: 4 pages max single column, with figures and references
- Submitted on bCourses under "Project Proposal" Assignment
- The progress report should follow the final report format, shown below. Of course, incomplete sections are expected.

2.4 Final Report [10 pts]

The project report parameters are as follows:

- Page limits: 15 pages max single column, or 8 pages double column (IEEE format) with figures and references
- Submitted on bCourses under "Project Report" Assignment

The format must follow the outline below:

(I) **[Title & Team Member Names]**

(II) **[Abstract]** Summarize the project in 200 words or less.

(III) **[Introduction]**

  (a) **[Motivation & Background]** This section provides answers to the following questions. Why is this topic interesting and important to study? What are the challenges associated with managing this particular energy system? Teams may optionally indicate how their previous experiences uniquely position themselves to study this topic. Teams may also indicate how this topic synergistically combines with their own research, other classes, etc.

  (b) **[Relevant Literature]** Summarize the key references that provide relevant background for your project topic. These references should be included in an enumerated list at the end of the document. These references can include published articles, textbooks, etc.

  (c) **[Focus of this Study]** Provide a precise statement of this study's focus, contextualized within the broader energy issues and related literature.

(IV) **[Technical Description]** The bulk of the report is the technical description. Describe, in concise yet technical detail, the methods, models, parameters, formulations, algorithms, results, etc. Use descriptive figures. The adage "a picture is worth a thousand words" holds true in technical writing. Use mathematics and equations. Mathematics provides a concrete and precise description, and avoids the subjectivity of word descriptions.

(V) **[Discussion]** Provide a thoughtful discussion on the results obtained? How does it advance sustainability in energy systems? What new aspects does it elucidate? How are systems and control tools uniquely positioned to answer these questions?

(VI) **[Summary]** Summarize the project's aim and results. A reader should understand the main ideas by only reading the abstract and summary.

2.5 Symposium [8 pt]

You will prepare a poster/project board, and deliver an oral presentation. More details TBA.

2.6 Self/Team Eval [1 pt]

Complete the associated survey. A link will be distributed during RRR week.

3 Sample Project Ideas

The following are sample project ideas. The intent is to seed your creativity. You are not required to select one of these projects, nor are you required to follow the idea exactly. Project reports from previous years are also supplied on bCourses. For any of these specific projects, the instructional staff can provide more focused advising. Keep in mind, this is a course project. *The scope should be sufficiently small yet rich to render reasonable results by the end of the semester.* That said, excellent projects/reports *could* become research conference papers. For these exceptional cases, I am delighted to co-author and sponsor the paper.

3.1 Oakland EcoBlock Microgrid Configuration

Application: Electric microgirds
Systems and Control Tool: Mathematical Modeling, Optimization, Optimal Control
Useful references: See "Files/Project/Oakland Ecoblock/" directory of bCourses.

The main thesis of the Oakland EcoBlock is: Design and coordination at the block scale provides opportunities to improve levelized energy costs beyond a fully decentralized model and (in particular when one incorporates transmission and distribution costs) beyond a centralized renewable model. This task focuses on identifying and evaluating candidate designs and control strategies that work toward this goal.

This project team will interact with colleagues involved in the EcoBlock project. Your main task is to evaluate the advantages and disadvantages of various electric topologies for the EcoBlock (see e.g. Fig. 1). The topologies include a centralized flywheel energy storage device, rooftop photovoltaics, and a central EV charging station. The system includes a DC circuit and an AC circuit. The question is how to design this circuit, and what are the advantages/disadvantages of various topologies.

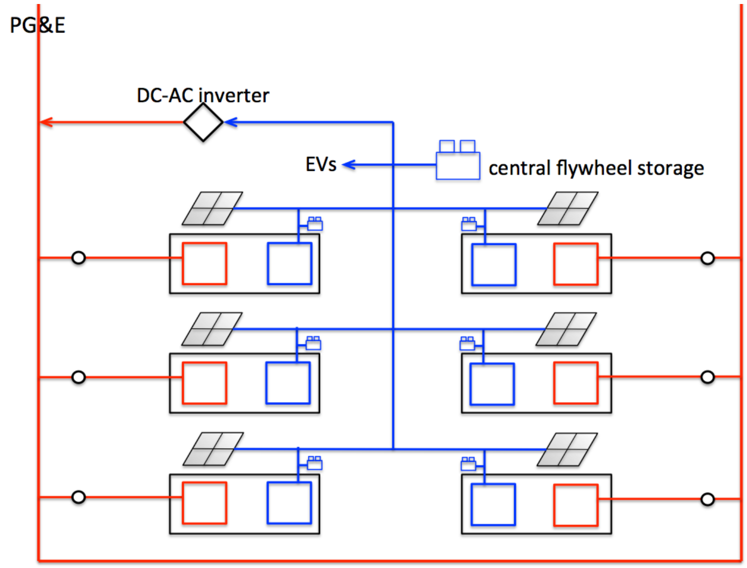

Figure 1: Sample topology of EcoBlock electric microgrid.

3.2 Smart Home Energy Management

Application: Buildings, homes
Systems and Control Tool: Control, Optimization (linear programming `linprog`, quadratic programming `quadprog`)
Useful references: [1, 2]

Consider a smart home that consists of

- Photovoltaic generation
- Stationary battery storage (e.g., second-life batteries)
- Plug-in electric vehicle
- Standard home loads (e.g. HVAC, dryer, refrigerator, lighting)

The goal is to optimize energy management over a 24-hour period to minimize electric utility costs. Ideally, one wishes to utilize only photovoltaic power. However, demand does not match generation. One may use the stationary battery storage to decouple generation from demand. However, any mismatch between demand,

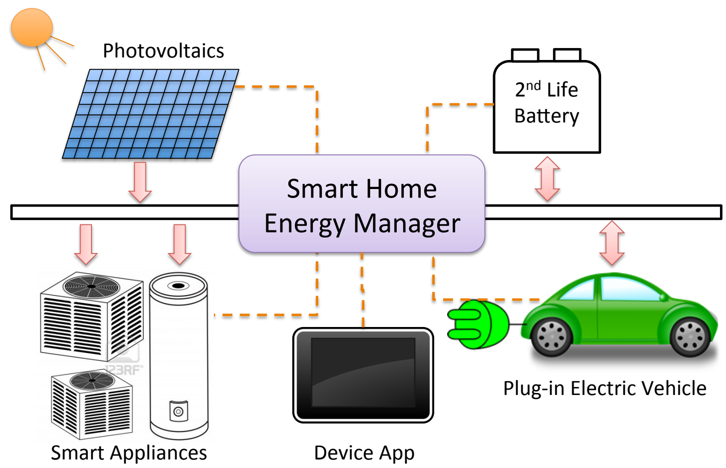

Figure 2: The smart home integrates renewable generation (e.g. PVs), advanced energy storage (e.g. second-use batteries), smart appliances (e.g. water heaters, HVAC, dryers), and plug-in electric vehicles.

battery power, and PV generation is supplied by power from the grid. Mathematically, the problem can be formulated as

$$
\begin{aligned}
\min \quad & \sum_{k=0}^{N} c(k) P^{dem}(k) \\
\text{s. to} \quad & P^{dem}(k) = P^{pv}(k) + P^{grid}(k) + P^{batt}(k) \\
& E(k+1) = E(k) + \Delta t \cdot P^{batt}(k) \\
& E(0) = E(N)
\end{aligned}
$$

where k indexes time, $c(k)$ is the time-varying cost of electricity, and $P^{grid}, P^{dem}, P^{pv}, P^{batt}$ are the grid power, home power demand, PV power generation, and battery power, and $E(k)$ is the battery energy level. Variable P^{batt} is controllable. Variables P^{pv}, P^{dem} are unknown beforehand, but can be predicted using forecasting models trained on historical data. Grid power P^{grid} is the resultant value necessary to ensure power balance, and is ultimately penalized.

3.3 Building Load Forecasting

Application: Buildings
Systems and Control Tool: Modeling, Parameter ID (i.e. "real-time regression")
Useful references: [2, 3, 4] and Eric Burger

This project investigates load forecasting algorithms using readily available data streams, such as smart meter data and Internet-based weather feeds. We seek two specific innovations. First, by leveraging cloud-based application programming interfaces (APIs), the algorithm anticipates and adapts to changing environmental conditions. Second, it is well-known that no "silver-bullet" model accurately forecasts power demand for all residential buildings, due to unique building construction, occupancy patterns, and energy use behaviors. However, certain models may produce "useful" forecasts in certain observable situations (e.g. weekday routine vs. holidays). Therefore, this task will pursue an "ensemble" regression method that trains and validates multiple forecasting models [5], and selects the best (in some sense) for each predictive control step.

3.4 The Building Energy Disaggregation Problem

Application: Buildings
Systems and Control Tool: Modeling, State Estimation
Useful references: [6, 7]

Energy disaggregation, also known as non-intrusive load monitoring (NILM), is the task of separating aggregate energy data for a whole building into the energy data for individual appliances. Studies have shown that simply providing disaggregated data to the consumer improves energy consumption behavior. However, placing individual sensors on every device in a home is not presently a practical solution. Disaggregation provides a feasible method for providing energy usage behavior data to the consumer which utilizes currently existing infrastructure.

3.5 Smart PEV Charger

Application: Transportation, Grid
Systems and Control Tool: Optimization (linear programming `linprog`, quadratic programming `quadprog`)
Useful references: [8, 9], Poster outside my lab (611 Davis)

Consider a plug-in electric vehicle (PEV), such as the one shown in Fig. 3. This vehicle is used for daily commuting, and remains plugged-in when not driving. During plug-in the PEV has the opportunity to charge. However, the cost of electricity varies throughout the day. The goal is to minimize charging cost in the presence of time-varying price, subject to the energy/mobility needs of the PEV driver. That is, the trivial solution is to never charge. However, sufficient charge is necessary to ensure the driver's mobility needs are satisfied. Consequently, charging can be formulated as an optimization problem – namely quadratic programming or linear programming.

Figure 3: [LEFT] Autolib vehicles, for example, could benefit from smart charging. [RIGHT] Example of an airborne wind energy generator by Altaeros Energies.

3.6 Review, Modeling, or Control of Airborne Wind Energy

Application: Grid
Systems and Control Tool: Modeling
Useful references: [10], and references therein

Wind energy has emerged as a promising source of renewable energy, both in terms of economics and performance. Installations of wind turbines are growing rapidly across the world, in both on-shore and off-shore locations. There is, however, a third emerging location – high altitudes. Airborne wind turbines (AWT) are devices that generate power from wind speeds at high altitudes. The key concept is that wind speeds are notably higher at altitude, and the cost of building a support structure can be significantly reduced by building aerial devices. The key challenge, however, is control. This project would review the various AWT technologies, provide the basic mathematical models, and outline the various control issues.

3.7 Energy Management of Wind-Diesel-Storage Systems

Application: Grid
Systems and Control Tool: Modeling, Optimization, Control
Useful references: [10, 11], and references therein

In rural or developing communities, airborne wind energy (AWE) provides a desirable alternative to existing diesel fuel generators. However, AWE suffers from strong intermittency that must be balanced with other sources. This project examines the energy management problem for a micro grid system consisting of two generators: diesel (dispatchable) & AWE (non-dispatchable); battery energy storage; and electricity loads.

The problem is to minimize diesel fuel use while providing reliable electricity service, given uncertainty in the AWE resource.

3.8 Shared Vehicle Rebalancing Problem

Application: Transportation
Systems and Control Tool: Modeling, Optimization
Useful references: [12, 13] and references therein

Vehicle sharing systems are quickly proliferating into major urban centers across the world. This proliferation is paralleled by open access to usage data – especially for shared bicycle systems, e.g. Citi Bike shown in Fig. 4. This provides an interesting opportunity for engineers to innovate on this open data.

A particular problem of interest for these sharing companies is the so-called rebalancing problem. Since flow from one station to another is seldom matched by flows in the reverse direction, a bicycle fleet can become spatially imbalanced over time. This leads to lower levels of service for users who must seek alternate stations to park or check out vehicles. This project would develop a network model of a small bicycle sharing systems, in which available bicycles serve as the state variable. Moreover, one could develop a stochastic model of demand identified from open data. These models could then be used to formulate an optimization problem that addresses the rebalancing problem.

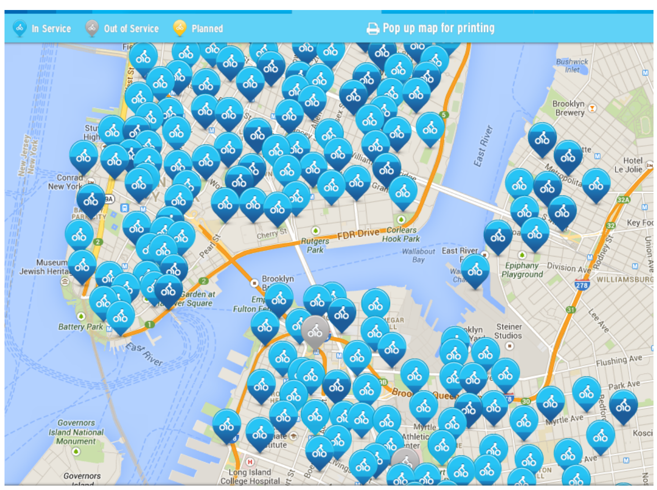

Figure 4: Map of Citi Bike system, with indicators of available bikes at each station.

3.9 Optimal Vehicle-to-Grid Aggregator with Heterogeneous Price/Comfort Levels

Application: Transportation, Grid
Systems and Control Tool: Modeling, Control
Useful references: [14, 8] and GSI Caroline Le Floch
In association with CE264, Behavioral Modeling

A vehicle-to-grid (V2G) capable electric vehicle (EV) communicates with the grid, stores energy, and can return energy to the electric grid. Aggregators manage a fleet of EVs and may pay drivers to use their vehicle as a storage device. Proposed work plan:

- Behavioral Modeling: find the relation between comfort and price (how much one driver should be paid to give 1% State Of Charge (SOC) to the aggregator)
- Control and Optimization: find the maximum profit of the aggregator with given prices and SOC flexibility

3.10 Quantifying the benefits of Demand Response

Application: Grid
Systems and Control Tool: Modeling
Useful references: [15, 16] and GSI Caroline Le Floch
In association with CE264, Behavioral Modeling

According to the Federal Energy Regulatory Commission, demand response (DR) is defined as: "Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized." There are different types of Demand Response programs (price based, incentive based). Proposed work plan:

- Behavioral Modeling: quantify the adoption of different Demand Response programs in the population
- Control and Optimization: quantify the cost / energy savings allowed by different Demand Response Programs

3.11 Optimal charging of an electric car-sharing fleet

Application: Transportation, Grid
Systems and Control Tool: Optimization, Control
Useful references: [17, 18, 19] and GSI Caroline Le Floch

In a car sharing system, vehicles are dispatched between stations and are occasionally rented by customers. What is the optimal charging schedule of cars to maximize the profit of the car sharing system?

- Behavioral Modeling: quantify the adoption of different Demand Response programs in the population
- Control and Optimization: quantify the cost / energy savings allowed by different Demand Response Programs

3.12 Chance constrained optimization of Electric Vehicle charging: how much can we win by knowing exact schedules of drivers?

Application: Transportation, Grid
Systems and Control Tool: Optimization, Control
Useful references: [8, 9, 20, 21] and GSI Caroline Le Floch
http://www.eecs.berkeley.edu/ elghaoui/Teaching/EE227A/lecture24.pdf

Chance constrained optimization is a method to deal with uncertainties and random processes in systems. The uncertainty about driver schedules can be modeled as probabilistic sets, and the optimal EV charging is a chance constrained optimization problem. The result of chance-constrained programming is suboptimal in comparison with deterministic programming; how can we quantify the loss due to uncertainties?

3.13 Maximum Power Point Tracking in Photovoltaics

Application: Grid
Systems and Control Tool: Control, Real-time optimization
Useful references: [22, 23]

Photovoltaic (PV) arrays convert solar energy into electrical energy. Interestingly, the output power is a nonlinear function of PV array voltage, and exhibits a unique maximum power point. This maximum power point, however, shifts due to changing temperature, shading, and solar irradiation. This potential project investigates algorithms to track the maximum power point in realtime, as shown in Fig. 5.

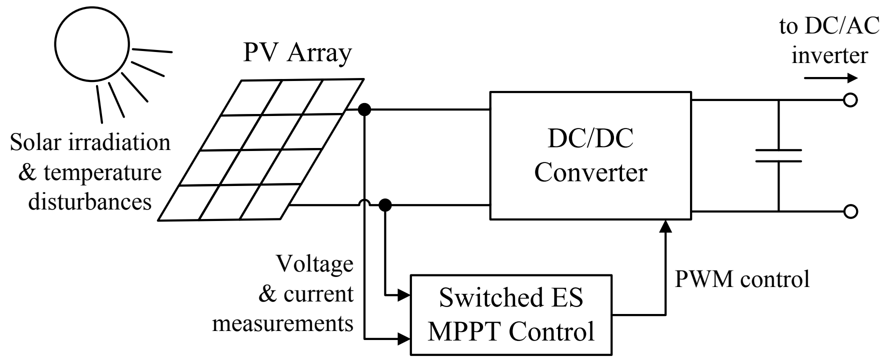

Figure 5: PV System.

3.14 Battery State-of-Charge Estimation

Application: Transportation, Grid, Wireless Devices
Systems and Control Tool: Estimation
Useful references: [24, 25, 26]

Battery management systems (BMS) in your smartphone, tablet, laptop, PEV, grid-scale energy storage, etc. must estimate the battery's current charge level. This project exercises model and estimation design, e.g. Kalman filters. One may utilize the linearized equivalent circuit model from HW1 in combination with the Kalman filter discussed in class to develop an estimator. This estimator can be tested on real-world battery data obtain from the instructor. Students may evaluate the efficacy of the estimator under different operating conditions, such as fast charging or extreme charge levels.

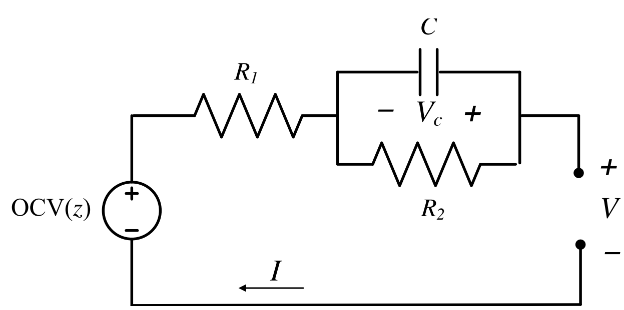

Figure 6: OCV-R-RC Equivalent circuit model of a battery. Includes an open circuit voltage in series with a resistance, in series with a resistor-capacitor pair.

3.15 Optimal-Safe Fast Charging of Batteries

Application: Transportation, Grid, Wireless Devices
Systems and Control Tool: Optimization, Control
Useful references: [27]

Imagine completely recharging your EV/smartphone battery in just 10-20 minutes. This is commonly avoided, because such fast charging rapidly degrades the battery. However, we can use optimization and control to minimize fast charge time, subject to safe operating constraints. This topic combines the equivalent circuit model in Fig. 6 (HW1) with dynamic programming in CH5.

Note: These references are downloadable by searching Google Scholar on the UCB campus network

References

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