The Final Oral Examination
for the Degree of

DOCTOR OF PHILOSOPHY
(Department of Electrical and Computer Engineering)

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“Demand Response in Smart Grid”

Friday, March, 13, 2015
2:30 PM
Engineering/Computer Science Building, Room 467

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Abstract
Conventionally, to support varying power demand, the utility company must prepare to supply more electricity than actually needed, which causes inefficiency and waste. With the increasing penetration of renewable energy which is intermittent and stochastic, how to balance the power generation and demand becomes even more challenging. Demand response, which reschedules part of the elastic load in users’ side is a promising technology to increase power generation efficiency and reduce costs. However, how to coordinate all the distributed heterogeneous elastic loads efficiently is a major challenge and sparks numerous research efforts. In this thesis, we investigate different methods to provide demand response and improve power grid efficiency.

First, we consider how to schedule the charging process of all the Plugged-in Hybrid Electrical Vehicles (PHEVs) so that demand peaks caused by PHEV charging are flattened. Existing solutions are either centralized which may not be scalable, or decentralized based on real-time pricing (RTP) which may not be deployed immediately for many markets. Our proposed PHEV charging approach does not need complicated, centralized control and can be executed online in a distributed manner. In addition, we extend our approach and apply it to the distribution grid to solve the bus congestion and voltage drop problems by controlling the access probability of PHEVs. One of the advantages of our algorithm is that it does not need accurate predictions on base load and future users’ behaviors. Furthermore, it is deployable even when the grid size is large.

Different from PHEVs, whose future arrivals are hard to predict, there is another category of elastic load, such as Heating Ventilation and Air-Conditioning (HVAC) systems, whose future status can be predicted based on the current status and control actions. How to minimize the power generation cost using this kind of elastic load is also an interesting topic to the power companies. Existing work usually used HVAC to do the load following or load shaping based on given control signals or objectives. However, optimal external control signals may not always be available. Without such control signals, how to make a
tradeoff between the fluctuation of non-renewable power
 generation and the limited demand response potential of the
 elastic load, while still guaranteeing user comfort level, is still an
 open problem. To solve this problem, we first model the
temperature evolution process of a room and propose an
approach to estimate the key parameters of the model. Then,
based on the model predictive control, a centralized and a
distributed algorithm are proposed to minimize the fluctuation and
maximize the user comfort level. In addition, we propose a
dynamic water level adjustment algorithm to make the demand
response always available in two directions. Extensive simulations
based on practical data sets show that the proposed algorithms
can effectively reduce the load fluctuation.

Both randomized PHEV charging and HVAC control algorithms
discussed above belong to direct or centralized load shaping,
which has been heavily investigated. However, it is usually not
clear how the users are compensated by providing load shaping
services. In the last part of this thesis, we investigate indirect load
shaping in a distributed manner. On one hand, we aim to reduce
the users’ energy cost by investigating how to fully utilize the
battery pack and the water tank for the Combined Heat and Power
(HP) systems. We first formulate the queueing models for the
HP systems, and then propose an algorithm based on the
Lyapunov optimization technique which does not need any
statistical information about the system dynamics. The optimal
control actions can be obtained by solving a non-convex
optimization problem. We then discuss when it can be converted
into a convex optimization problem. On the other hand, based on
the users’ reaction model, we propose an algorithm, with a time
complexity of $O(\log n)$, to determine the RTP for the power
company to effectively coordinate all the HP systems and
provide distributed load shaping services.

Awards, Scholarships, Fellowships
2014 UVIC Three Minute Thesis competition 2nd prize
(Engineering and Computer Science group)
2014 IEEE Infocom Student Travel grant
2014 University of Victoria GSS student travel grant
2011 University of Victoria Graduate Student Fellowship.
Presentations


Publications

Journal Papers


Conference Papers


Submitted Papers