Papers Reviewed for MSc. Thesis

Christian Baumann

July 11, 2019

1 Introduction

This document contains a list of papers I consider to be interesting or related to my Master's thesis. The order of the described papers is quite arbitrary.

2 Categories

This section lists papers that are similar in certain aspects.

2.1 Reinforcement Learning

The following papers use some sort of reinforcement learning to tackle the control problem: [Rue+17; WW11; WYZ17; Che+18; CLK15; CLK13; LP12; SDD19; KPL18; Van+15; Ern+09].

2.2 Convex Optimization Based Control

E.g. MPC or Linear programming. [Ern+09]

2.3 Electric Vehicles

2.4 Residental Appliances

E.g. HVAC, heat pumps, water heaters, natural ventilation.

3 Summaries

This sections provides titles and very short summaries of the papers.

3.1 "Reinforcement Learning Based Energy Management Algorithm for Smart Energy Buildings", [KL18]

Energy management system for building equipped with PV, V2G enabled EV and an energy storage system (ESS). Only controlling whether to buy / sell energy and charge / discharge ESS, not controlling EV charging, but no known arrival / departure time of EV. Using real-time electricity prices and minimizing total cost. Q-learning, ϵ-greedy, with initialization of Q-table as immediate reward to speed up convergence. Simulated in Matlab.

3.2 "Residential Demand Response of Thermostatically Controlled Loads Using Batch Reinforcement Learning", [Rue+17]

Control of either electric water heater or heat pump using RL. Extension of fitted Q-iteration that can take into account forecasted data. Also: Policy improvement using expert knowledge and 1-day ahead planning using Monte Carlo search method.

3.3 "Joint Optimization of Electric Vehicle and Home Energy Scheduling Considering User Comfort Preference", [NL14]

Electric vehicle and home energy scheduling, minimizing electricity costs, 1-day ahead optimization using linear programming and a simplified dynamics model with known driving patterns and electricity prices. Comparing one household with one EV and multiple, bidirectional charging, simulation only.

3.4 "Energy Management for Households With Solar Assisted Thermal Load Considering Renewable Energy and Price Uncertainty", [NNL15]

Joint home energy management minimizing electricity costs taking into account real-time electricity prices. Stochastic programming used to find control policy. Loads include HVAC, EV (unidirectional charging only), washing machine, dryer, additionally PVs provide electricity and a heat tank is used to store energy.

3.5 "Distributed Online Energy Management for Data Centers and Electric Vehicles in Smart Grid", [YJZ16]

Joint energy management of data centers and electric vehicles of employees, unidirectional charging only, 1-day ahead planning with convex optimization. Simulation only.

3.6 "Real-time vehicle-to-grid control algorithm under price uncertainty", [WW11]

RL used to control EV by either charging, discharging of provide frequency regulation to the grid provider. ϵ-greedy Q-learning, trained using separately either MC pricing or past pricing data, no future prices known, control based on only current (and past) price. Maximizing profit of the EV owner.

3.7 “Deep reinforcement learning for building HVAC control”, [WYZ17]

As title suggests, deep RL for HVAC control in building. Q-learning, ϵ-greedy, using EnergyPlus simulation tool for training and evaluation. No dynamics model.

3.8 “Optimal control of HVAC and window systems for natural ventilation through reinforcement learning”, [Che+18]

Model-free Q-learning to control HVAC and window systems. Learned and evaluated on a simulation and compared to a heuristic approach. Only current data included in state, no future knowledge of temperature, wind or solar irradiation included.

3.9 “Optimization of plug-in electric vehicle charging with forecasted price”, [CLK15]

PEV charging optimization minimizing electricity price. Uses known electricity prices for one day and forecasted prices for second day. Fitted Q-iteration with kernel based approximation of value iteration. Simulation only.

3.10 “Scheduling of plug-in electric vehicle battery charging with price prediction”, [CLK13]

PEV charging optimization minimizing electricity price. Uses known electricity prices for one day and forecasted prices for second day. SARSA with eligibility traces, ϵ-greedy. Simulation with real world data.

3.11 “Bidirectional Energy Trading and Residential Load Scheduling with Electric Vehicles in the Smart Grid”, [Kim+13]

Residental and EV load, supporting bidirectional charging. 1-day ahead (distributed) convex optimization minimizing electricity costs, known but varying electricity prices. Worst-case-uncertainty approach to tackle uncertainty.

3.12 “Impact analysis of vehicle-to-grid technology and charging strategies of electric vehicles on distribution networks - A review”, [HKR15]

V2G and charging strategy analysis, high level, no concrete algorithms how to coordinate charging, look at references for that.

3.13 “An intelligent battery controller using bias-corrected Q-learning”, [LP12]

Method to tackle the bias induced by taking the max of the estimated Q function in the Q-learning algorithm, leading to improved convergence. Tested for battery control with the goal of maximizing profit with varying electricity prices.

3.14 “Definition and evaluation of model-free coordination of electrical vehicle charging with reinforcement learning”, [SDD19]

Joint control of multiple charging stations with the goal of load flattening. Probabilistic arrival of new EVs only. Fitted Q-iteration RL algorithm used for optimization, trained based on past experience only. Simulation using real-world data.

3.15 “Control and Power Management of a Grid Connected Residential Photovoltaic System with Plug-in Hybrid Electric Vehicle (PHEV) Load”, [GK09]

Residental PV system and PHEV charging controller is designed using fixed load profiles and solar irradiance data. Classical control, simulation only, unidirectional charging. Worst-day robustness.

3.16 “Mobility-Aware Vehicle-to-Grid Control Algorithm in Microgrids”, [KPL18]

Coordinating multiple microgrids with EVs moving between them. Bidirectional charging supporting EVs can be used to transport energy from one to another microgrid. Solved with dynamics model and value iteration *and* model-free reinforcement learning (Q-learning).

3.17 “Reinforcement Learning of Heuristic EV Fleet Charging in a Day-Ahead Electricity Market”, [Van+15]

RL for 1-day ahead charging planning of an EV fleet. Fitted Q-iteration, Boltzmann exploration, compared to stochastic programming that uses exact EV information. RL controlling whole fleet demand, partitioning to individual EVs by heuristic.

3.18 "Reinforcement Learning Versus Model Predictive Control: A Comparison on a Power System Problem", [Ern+09]

Comparing MPC to RL (fitted Q-iteration) for a deterministic problem. Extra-Tree regressor used as supervised learning algorithm for FQI. RL shows comparative performance without knowing the system model. RL even shows lower CPU time for online application compared to MPC with large time horizons.

3.19 "Data-driven model predictive control using random forests for building energy optimization and climate control", [Sma+18]

Data driven MPC, learning a dynamics model by a regression tree or random forest with decision tree partitioning disturbance and state variables only. Then in each leave learn the dynamics model, affine linear in control variables. Then use this model for receding horizon control as in MPC. Applied to building control.

References

[Che+18] Yujiao Chen et al. "Optimal control of HVAC and window systems for natural ventilation through reinforcement learning". In: *Energy and Buildings* 169 (2018), pp. 195 –205. ISSN: 0378-7788. DOI: https://doi.org/10.1016/j.enbuild.2018.03.051. URL: http://www.sciencedirect.com/science/article/pii/S0378778818302184.

[CLK13] A. Chiş, J. Lundén, and V. Koivunen. "Scheduling of plug-in electric vehicle battery charging with price prediction". In: *IEEE PES ISGT Europe 2013*. 2013, pp. 1–5. DOI: 10.1109/ISGTEurope.2013.6695263.

[CLK15] A. Chiş, J. Lundén, and V. Koivunen. "Optimization of plug-in electric vehicle charging with forecasted price". In: *2015 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*. 2015, pp. 2086–2089. DOI: 10.1109/ICASSP.2015.7178338.

[Ern+09] D. Ernst et al. "Reinforcement Learning Versus Model Predictive Control: A Comparison on a Power System Problem". In: *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)* 39.2 (2009), pp. 517–529. ISSN: 1083-4419. DOI: 10.1109/TSMCB.2008.2007630.

[GK09] Y. Gurkaynak and A. Khaligh. "Control and Power Management of a Grid Connected Residential Photovoltaic System with Plug-in Hybrid Electric Vehicle (PHEV) Load". In: *2009 Twenty-Fourth Annual IEEE Applied Power Electronics Conference and Exposition*. 2009, pp. 2086–2091. DOI: 10.1109/APEC.2009.4802962.

[HKR15] Salman Habib, Muhammad Kamran, and Umar Rashid. "Impact analysis of vehicle-to-grid technology and charging strategies of electric vehicles on distribution networks - A review". In: *Journal of Power Sources* 277 (2015), pp. 205 –214. ISSN: 0378-7753. DOI: https://doi.org/10.1016/j.jpowsour.2014.12.020. URL: http://www.sciencedirect.com/science/article/pii/S0378775314020370.

[Kim+13] B. Kim et al. "Bidirectional Energy Trading and Residential Load Scheduling with Electric Vehicles in the Smart Grid". In: *IEEE Journal on Selected Areas in Communications* 31.7 (2013), pp. 1219–1234. ISSN: 0733-8716. DOI: 10.1109/JSAC.2013.130706.

[KL18] Sunyong Kim and Hyuk Lim. "Reinforcement Learning Based Energy Management Algorithm for Smart Energy Buildings". In: *Energies* 11.8 (2018). ISSN: 1996-1073. DOI: 10.3390/en11082010. URL: https://www.mdpi.com/1996-1073/11/8/2010.

[KPL18] H. Ko, S. Pack, and V. C. M. Leung. "Mobility-Aware Vehicle-to-Grid Control Algorithm in Microgrids". In: *IEEE Transactions on Intelligent Transportation Systems* 19.7 (2018), pp. 2165–2174. ISSN: 1524-9050. DOI: 10.1109/TITS.2018.2816935.

[LP12] D Lee and W.B. Powell. "An intelligent battery controller using bias-corrected Q-learning". In: *Proceedings of the National Conference on Artificial Intelligence* 1 (Jan. 2012), pp. 316–322.

[NL14] D. T. Nguyen and L. B. Le. "Joint Optimization of Electric Vehicle and Home Energy Scheduling Considering User Comfort Preference". In: *IEEE Transactions on Smart Grid* 5.1 (2014), pp. 188–199. ISSN: 1949-3053. DOI: 10.1109/TSG.2013.2274521.

[NNL15] H. T. Nguyen, D. T. Nguyen, and L. B. Le. "Energy Management for Households With Solar Assisted Thermal Load Considering Renewable Energy and Price Uncertainty". In: *IEEE Transactions on Smart Grid* 6.1 (2015), pp. 301–314. ISSN: 1949-3053. DOI: `10.1109/TSG.2014.2350831`.

[Rue+17] F. Ruelens et al. "Residential Demand Response of Thermostatically Controlled Loads Using Batch Reinforcement Learning". In: *IEEE Transactions on Smart Grid* 8.5 (2017), pp. 2149–2159. ISSN: 1949-3053. DOI: `10.1109/TSG.2016.2517211`.

[SDD19] N. Sadeghianpourhamami, J. Deleu, and C. Develder. "Definition and evaluation of model-free coordination of electrical vehicle charging with reinforcement learning". In: *IEEE Transactions on Smart Grid* (2019), pp. 1–1. ISSN: 1949-3053. DOI: `10.1109/TSG.2019.2920320`.

[Sma+18] Francesco Smarra et al. "Data-driven model predictive control using random forests for building energy optimization and climate control". In: *Applied Energy* 226 (2018), pp. 1252 –1272. ISSN: 0306-2619. DOI: `https://doi.org/10.1016/j.apenergy.2018.02.126`. URL: `http://www.sciencedirect.com/science/article/pii/S0306261918302575`.

[Van+15] S. Vandael et al. "Reinforcement Learning of Heuristic EV Fleet Charging in a Day-Ahead Electricity Market". In: *IEEE Transactions on Smart Grid* 6.4 (2015), pp. 1795–1805. ISSN: 1949-3053. DOI: `10.1109/TSG.2015.2393059`.

[WW11] Wenbo Shi and V. W. S. Wong. "Real-time vehicle-to-grid control algorithm under price uncertainty". In: *2011 IEEE International Conference on Smart Grid Communications (SmartGridComm)*. 2011, pp. 261–266. DOI: `10.1109/SmartGridComm.2011.6102330`.

[WYZ17] T. Wei, Yanzhi Wang, and Q. Zhu. "Deep reinforcement learning for building HVAC control". In: *2017 54th ACM/EDAC/IEEE Design Automation Conference (DAC)*. 2017, pp. 1–6. DOI: `10.1145/3061639.3062224`.

[YJZ16] L. Yu, T. Jiang, and Y. Zou. "Distributed Online Energy Management for Data Centers and Electric Vehicles in Smart Grid". In: *IEEE Internet of Things Journal* 3.6 (2016), pp. 1373–1384. ISSN: 2327-4662. DOI: `10.1109/JIOT.2016.2602846`.