# Daniel's Super Cool and overly long title

Daniel Mortensen, Jacob Gunther

***Abstract*—TODO: add abstract**

***Index Terms*—TODO: Add Keywords**

## I. Introduction

The goal of public transportation is to provide transit services using cost effective and environmentally sound methods. To better meet these needs, electric buses are becoming more common. Benefits include the use of renewable energy, reduced emissions, and fewer maintenance costs [14]. However, there are also extended charge times, electrical expenses, increased loads on power infrastructure [16], [6], [3], and limited battery lifespans [9].

Because charging requires time, buses have limited availability, and there are limited charging resources, charge times must be scheduled with care. This work addresses the problem of charge scheduling and proposes a methodology with the following considerations: bus availabilty, external loads, fiscal expenses, day/night charging, and variable charge rates. To the best of our knowledge, this is the first time these methods have been included in the same framework.

The remainder of this paper is organized as follows... ===insert stuff here===

## II. Literature Review

We acknowledge the existance of additional contributions, such as minimizing costs for startup infrastructure [17], and preserving battery lifespan [9]. However, as these are not relevent to this work, we consider them outside the scope of this review. We further acknowledge that some works cited herein contain solutions to several of these problems, such as in [20], but for sake of organization, we list them in the most relevent context.

### A. Battery Charging

Here we consider solutions to empty batteries and focus our attention on either battery replacement or charging methods. We also refer to charging methods as either static (at rest) or dynamic (in motion).

Because charge times can significantly complicate logistics, [19] and [11] give methods for exchanging spent with charged batteries. The benefits include minimal down time as refueling can occur in a matter of minutes. Unfortunately, batteries can be cumbersome, and their exchange can be difficult. It also requires specialized tools, and could require automation.

Another alternative is to inductively charge buses while they traverse their routes [2], [11], [12], [5]. Unfortunately, this requires significant infrastructure which may not be available and is cost prohibitive for large systems.

Alternative solutions tend towards optimal planning. This allows for buses to charge in the traditional sense, minimizes additional infrastructure, and avoids the complexities of exchanging batteries. These approaches generally fall into one of three categories; reactive, hybrid, and global.

Reactive planning focuses strictly on presential circumstances. Methods of this type are computationally efficient, run in real-time, and are adaptable. These techniques generally stem from control theory and minipulate a current state to minimize cost. One such example includes the work done by [4], who uses comparable methodology to reduce demand on the power grid. This methodology however, does not account for global phenomena that require broader planning schemes and for the most part this class of technqiues remain unused for bus charging.

Another class of algorithms encompasses a limited number of projected events to improve decision making. This allows for a middle ground between simplicity and global planning and has proven useful in previous work [10], [1].

Global planning algorithms assume comlplete foreknowledge of future events and provide globally optimal plans [18],[7]. This class of algorithm requires more computation and is less flexible then reactive or hybrid approaches. However, the solutios are globally optimal and derive from insight unavailable to other algorithm classes.

### B. Cost Management

The final set of constraints aim to decrease load on the grid. Previous work has shown that the use of electric buses can significantly complicate local power management [3] [6]. Additinally, power demand generally increases the fiscal cost from a billing perspective. [8] has provided methodology for forcasing the load on the grid. These types of models often form the basis for power distribution algorithms. For example, [15] gives an approach to minimize grid demand, but requires foreknowledge of uncontrolled loads. [4] takes a different approach and observes real-time data to control the charge rates of connected buses. [13] also operates in the real-time sense but uses on-board batteries to mitigate the effects of rapid charging.

## III. Graph Info

1. Describe basic structure a. nodes i. what this is, and how it relates to the problem. 1. a node represents charging options, 0th is no charge, i,j (i ¿ 0) represents the option to charge bus i at time j. This can be thought of as some aspect of state (include picture). Make sure to mention how nodes indicate bus schedule b. edges i. what this is, and how it relates to the problem. 1. an edge represents how a charger gets from one node to the next. 2. Give example of node

to node connection and what this means (include picture) 2. Describe represenation a. adjacency matrix 3. How this fits in a. Associated variables for linear program b. How these work with adjacency matrix for flow constraints c. How these work with adjacency matrix for group constraints

## IV. Battery State of Charge

1. remind how charging relates to the graph 2. introduce $d_{i,j}$ and $g_{i,j}$ and show how they relate to the graph (picture for d for each node), (second picture for g for each charging timestep) 3. Charging a. Introduce variable rate charging – make sure to mention this as a contribution b. Show how this adds edges to the graph (show picture) 4. Discharging a. Show how delta is incorporated b. mention that delta is taken from real data (contribution)

## V. Fiscal Rate Schedule

general introduction with details for demand and consumption charge and how these relate to the end-of-the-month billing. a. external loads (contribution) b. consumption charge i. total energy in Kwh ii. on-peak vs off-peak iii. constraints for consumption charge c. demand charge i. average power in 15 minute window ii. on-peak vs facilities iii. constraints for on-peak and facilities charges d. total cost breakdown i. Show how Rocky Mountain Power uses these and what the cost weighting is.

## VI. Bus Fleet Operations

Overview of bus operations during the day vs the night a. night environment i. one charger per bus ii. slow chargers iii. single rate chargers iv. buses always available b. day environment i. limited number of chargers ii. fast/variable rates iii. limited charging availability c. multiple graphs to incorporate day vs night charging i. show picture to illustrate this ii. show SOC constraints to implement these relationships

## VII. Objective Function

## VIII. Gurobi & Usage

## IX. Results

## X. Future Work

## References


[1] Avishan Bagherinezhad et al. "Spatio-Temporal Electric Bus Charging Optimization With Transit Network Constraints". In: *IEEE Transactions on Industry Applications* 56.5 (Sept. 2020), pp. 5741–5749. ISSN: 0093-9994, 1939-9367. DOI: 10.1109/TIA.2020.2979132. URL: https://ieeexplore.ieee.org/document/9028116/ (visited on 11/13/2021).

[2] Bhagyashree J Balde and Arghya Sardar. "Electric Road system With Dynamic Wireless charging of Electric buses". In: *2019 IEEE Transportation Electrification Conference (ITEC-India)*. 2019 IEEE Transportation Electrification Conference (ITEC-India). Bengaluru, India: IEEE, Dec. 2019, pp. 1–4. ISBN: 978-1-72813-169-6. DOI: 10.1109/ITEC-India48457.2019.ITECINDIA2019-251. URL: https://ieeexplore.ieee.org/document/9080859/ (visited on 11/18/2021).

[3] T. Boonraksa et al. "Impact of Electric Bus Charging on the Power Distribution System a Case Study IEEE 33 Bus Test System". In: *2019 IEEE PES GTD Grand International Conference and Exposition Asia (GTD Asia)*. 2019 IEEE PES GTD Grand International Conference and Exposition Asia (GTD Asia). Bangkok, Thailand: IEEE, Mar. 2019, pp. 819–823. ISBN: 978-1-5386-7434-5. DOI: 10.1109/GTDAsia.2019.8716023. URL: https://ieeexplore.ieee.org/document/8716023/ (visited on 11/13/2021).

[4] Qifu Cheng et al. "A smart charging algorithm-based fast charging station with energy storage system-free". In: *CSEE Journal of Power and Energy Systems* (2020). ISSN: 20960042, 20960042. DOI: 10.17775/CSEEJPES.2020.00350. URL: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9171658 (visited on 11/19/2021).

[5] Blint Csonka. "Optimization of Static and Dynamic Charging Infrastructure for Electric Buses". In: *Energies* 14.12 (June 13, 2021), p. 3516. ISSN: 1996-1073. DOI: 10.3390/en14123516. URL: https://www.mdpi.com/1996-1073/14/12/3516 (visited on 11/13/2021).

[6] Sanchari Deb, Karuna Kalita, and Pinakeshwar Mahanta. "Impact of electric vehicle charging stations on reliability of distribution network". In: *2017 International Conference on Technological Advancements in Power and Energy ( TAP Energy)*. 2017 International Conference on Technological Advancements in Power and Energy (TAP Energy). Kollam: IEEE, Dec. 2017, pp. 1–6. ISBN: 978-1-5386-4021-0. DOI: 10.1109/TAPENERGY.2017.8397272. URL: https://ieeexplore.ieee.org/document/8397272/ (visited on 11/16/2021).

[7] Nader A. El-Taweel and Hany E. Z. Farag. "Incorporation of Battery Electric Buses in the Operation of Intercity Bus Services". In: *2019 IEEE Transportation Electrification Conference and Expo (ITEC)*. 2019 IEEE Transportation Electrification Conference and Expo (ITEC). Detroit, MI, USA: IEEE, June 2019, pp. 1–6. ISBN: 978-1-5386-9310-0. DOI: 10.1109/ITEC.2019.

8790598. URL: https://ieeexplore.ieee.org/document/8790598/ (visited on 11/19/2021).

[8] Qiang Gao et al. "Charging Load Forecasting of Electric Vehicle Based on Monte Carlo and Deep Learning". In: *2019 IEEE Sustainable Power and Energy Conference (iSPEC)*. 2019 IEEE Sustainable Power and Energy Conference (iSPEC). Beijing, China: IEEE, Nov. 2019, pp. 1309–1314. ISBN: 978-1-72814-930-1. DOI: 10.1109/iSPEC48194.2019.8975364. URL: https://ieeexplore.ieee.org/document/8975364/ (visited on 11/19/2021).

[9] Adnane Houbbadi et al. "Optimal Charging Strategy to Minimize Electricity Cost and Prolong Battery Life of Electric Bus Fleet". In: *2019 IEEE Vehicle Power and Propulsion Conference (VPPC)*. 2019 IEEE Vehicle Power and Propulsion Conference (VPPC). Hanoi, Vietnam: IEEE, Oct. 2019, pp. 1–6. ISBN: 978-1-72811-249-7. DOI: 10.1109/VPPC46532.2019.8952493. URL: https://ieeexplore.ieee.org/document/8952493/ (visited on 11/13/2021).

[10] Amra Jahic, Mina Eskander, and Detlef Schulz. "Preemptive vs. non-preemptive charging schedule for large-scale electric bus depots". In: *2019 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe)*. 2019 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe). Bucharest, Romania: IEEE, Sept. 2019, pp. 1–5. ISBN: 978-1-5386-8218-0. DOI: 10.1109/ISGTEurope.2019.8905633. URL: https://ieeexplore.ieee.org/document/8905633/ (visited on 11/16/2021).

[11] Shubham Jain et al. "Battery Swapping Technology". In: *2020 5th IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE)*. 2020 5th IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE). Jaipur, India: IEEE, Dec. 1, 2020, pp. 1–4. ISBN: 978-1-72818-867-6. DOI: 10.1109/ICRAIE51050.2020.9358366. URL: https://ieeexplore.ieee.org/document/9358366/ (visited on 11/18/2021).

[12] Seog Y. Jeong et al. "Automatic Current Control by Self-Inductance Variation for Dynamic Wireless EV Charging". In: *2018 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer (Wow)*. 2018 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer (WoW). Montral, QC, Canada: IEEE, June 2018, pp. 1–5. ISBN: 978-1-5386-2465-4. DOI: 10.1109/WoW.2018.8450926. URL: https://ieeexplore.ieee.org/document/8450926/ (visited on 11/18/2021).

[13] Inaki Ojer et al. "Development of energy management strategies for the sizing of a fast charging station for electric buses". In: *2020 IEEE International Conference on Environment and Electrical Engineering and 2020 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)*. 2020 IEEE International Conference on Environment and Electrical Engineering and 2020 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe). Madrid, Spain: IEEE, June 2020, pp. 1–6. ISBN: 978-1-72817-455-6. DOI: 10.1109/EEEIC/ICPSEurope49358.2020.9160716. URL: https://ieeexplore.ieee.org/document/9160716/ (visited on 11/16/2021).

[14] Kavuri Poornesh, Kuzhivila Pannickottu Nivya, and K. Sireesha. "A Comparative study on Electric Vehicle and Internal Combustion Engine Vehicles". In: *2020 International Conference on Smart Electronics and Communication (ICOSEC)*. 2020 International Conference on Smart Electronics and Communication (ICOSEC). Trichy, India: IEEE, Sept. 2020, pp. 1179–1183. ISBN: 978-1-72815-461-9. DOI: 10.1109/ICOSEC49089.2020.9215386. URL: https://ieeexplore.ieee.org/document/9215386/ (visited on 11/13/2021).

[15] Nan Qin et al. "Numerical analysis of electric bus fast charging strategies for demand charge reduction". In: *Transportation Research Part A: Policy and Practice* 94 (Dec. 2016), pp. 386–396. ISSN: 09658564. DOI: 10.1016/j.tra.2016.09.014. URL: https://linkinghub.elsevier.com/retrieve/pii/S096585641630444X (visited on 11/13/2021).

[16] Daniel Stahleder et al. "Impact Assessment of High Power Electric Bus Charging on Urban Distribution Grids". In: *IECON 2019 - 45th Annual Conference of the IEEE Industrial Electronics Society*. IECON 2019 - 45th Annual Conference of the IEEE Industrial Electronics Society. Lisbon, Portugal: IEEE, Oct. 2019, pp. 4304–4309. ISBN: 978-1-72814-878-6. DOI: 10.1109/IECON.2019.8927526. URL: https://ieeexplore.ieee.org/document/8927526/ (visited on 11/16/2021).

[17] Ran Wei et al. "Optimizing the spatio-temporal deployment of battery electric bus system". In: *Journal of Transport Geography* 68 (Apr. 2018), pp. 160–168. ISSN: 09666923. DOI: 10.1016/j.jtrangeo.2018.03.013. URL: https://linkinghub.elsevier.com/retrieve/pii/S0966692317306294 (visited on 11/13/2021).

[18] Justin Whitaker et al. "A Network Flow Approach to Battery Electric Bus Scheduling". In: (2021), p. 10.

[19] Xian Zhang and Guibin Wang. "Optimal dispatch of electric vehicle batteries between battery swapping stations and charging stations". In: *2016 IEEE Power and Energy Society General Meeting (PESGM)*. 2016 IEEE Power and Energy Society General Meeting (PESGM). Boston, MA, USA: IEEE, July 2016, pp. 1–5. ISBN: 978-1-5090-4168-8. DOI: 10.1109/PESGM.2016.7741893. URL: http://ieeexplore.ieee.org/document/7741893/ (visited on 11/18/2021).

[20] Dan Zhou et al. "Optimization Method of Fast Charging Buses Charging Strategy for Complex Operating Environment". In: *2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2)*. 2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2). Beijing: IEEE, Oct. 2018, pp. 1–6. ISBN: 978-1-5386-8549-5. DOI: 10.1109/EI2.2018.8582378. URL: https://ieeexplore.ieee.org/document/8582378/ (visited on 11/13/2021).