Abstract

In this paper, we evaluate a case study at the University of California, Riverside (UCR) that simulates different EV charging setups with their associated electric costs and CO\textsubscript{2}. The CO\textsubscript{2} are calculated with high resolution CAISO CO\textsubscript{2} emissions data in order to review the different emission levels from the different setups. Electric costs are also compared in order to see the different savings the consumer will have with the different setups. It was found that Level 2 charging has a minimal impact on electric costs and CO\textsubscript{2} emissions, which can be offsetted with EV pricing, and by replacing trips from internal combustion engine (ICE) vehicles. Level 3 charging does cause a higher output of emissions, it can double the demand costs by itself. While the CO\textsubscript{2} can be offset from the prevented ICE trips, a prevention of Level 3 charging during peak times must be implemented to prevent high demand costs.

Introduction

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\subsection{Background}

California is committed to reducing greenhouse gas emissions through various approaches. However, the two largest contributors to greenhouse gas emissions in California are transportation and electricity generation. In California,18.84 \% percent of 2022 vehicle sales were electric, \cite{ev\_sale\_percentage} and the state plans on banning internal combustion engine vehicles by 2035 \cite{ice\_ban}. At the same time, California is increasing the number of charging stations in the state, having over 13,737 stations \cite{ev\_stations\_CA}. Electric vehicle technology has improved, and new vehicles can charge in 20-60 minutes \cite{ev\_stats}. This is due to Level 3 charging, which can be as high as 350 kilowatts (kW), as opposed to Level 2 charging, which is capped at 19 kW \cite{ev\_stats}. While this innovation has led to a higher practicality for electric vehicles, it also leads to more difficulty for the owners of these chargers since they can create a tremendous amount of loads very quickly. Most Level 2 chargers consumers use are similar in load to an air conditioner. While California tries to increase clean energy penetration, it also needs to reduce the amount of GHG emissions produced by transportation through electrification. This leads to two conundrums: how will California add enough capacity for electrified transport, and how clean is the grid to minimize the amount of emissions associated with battery electric vehicles? One proposal to mitigate the strain on the grid is to keep electricity production and EV charging local by using microgrids. A microgrid is defined as: “‘a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode” As microgrids and EV chargers become ubiquitous, it is crucial to study the economic and environmental impacts EV charging, in particular fast charging, will have on microgrids.

\subsection{Literature Review}

In \cite{himabindu2021analysis}, Electric Vehicle Charging Stations (EVCS) are analyzed under different solar irradiation conditions. The study develops a demand and stochastic model, then performs a techno-economic assessment and analyzes the environmental impact of EVCS. The authors conclude that EVCS with solar's optimal configuration and investment costs are highly dependent on feed-in tariffs and the solar irradiation of the area. The CO\textsubscript{2} emissions were calculated on a per year basis, and do not deal with the variations of CO\textsubscript{2} emissions within a single day. Also, only energy charges were calculated with no demand costs calculations. \citen{yoon2017economic}, proposes a control algorithm is proposed that in different scenarios can minimize charging time or costs or maximize renewable energy use. The authors used a uniform distribution during peak times to model the charging loads, with only Level 2 charging at 3.3 kW and no Level 3 charging. An EV charging model is proposed in \cite{purvins2018electric}, that load shifts charging events from high peak times to low peak times. The authors found their current method does little to reduce peak load shaving, and solar production surplus may not be necessarily shifted to EVs due to their low availability at the time. The dataset was limited to one week ], with four EVs in a system with 10 buildings. In \cite{Khemir}, the authors run multiple scenarios with different self consumption rates, first comparing scenarios and then calculating emissions for each scenario.. The CO\textsubscript{2} emissions are calculated from whole life-cycle CO \textsubscript{2} emissions without a high time resolution. \cite{huang2023multi} uses the Non-dominated Sorting Genetic Algorithm-

II (NSGA-II) to analyze 4 different responses with 0 \% 10 \% 20 \% 30\% EV penetration and a Monte Carlo load profile. Results were remarkable, however CO\textsubscript{2} calculations were not explained. and the specific impacts of Level 2 vs Level 3 charging were not shown. \cite{tan2020multi} analyzes IEEE 9 and 14 nodes that forecast the EV loads one day ahead. The author use multiple microgrids to balance out EV charging within the system. Multi-objective energy management of multiple microgrids is used to orchestrate the operation.

This paper's analyzes the impacts different Level 2 and Level 3 charging have on the behavior of microgrids and the associated electric costs and CO\textsubscript{2} emissions in southern California. The simulation is run in open Modelica rather than being a purely calculated model. This paper also uses a higher time resolution data than most to calculate the CO\textsubscript{2} emissions every 15 minutes.

\subsection{Peak Shaving Strategy}

Peak shaving is a standard method for reducing high-demand charges. Since demand charges are based on only the maximum value over the entire month, \we assume the consumer wants to minimize the demand charges as much as possible. Our algorithm is based solely on cost savings for a typical microgrid. During flat-rate peak shaving, the algorithm looks at the amount of power being imported, if there is enough energy, and if the batteries can mitigate a fraction of that or the total amount. With TOU, peak shaving is prioritized more during on-peak times, and shifts demand to mid-peak and off-peak hours.

\subsection{CO\textsubscript{2} Emissions}

Our microgrid's solar production greatly overlaps with the local solar energy production within the larger grid. This leads to the problem within our microgrid, that while the grid gives off zero CO\textsubscript{2} emissions during solar peak hours, we still rely on the main electrical grid during off-peak hours, which is when there are higher CO\textsubscript{2} emissions. However, with a BESS, we can utilize renewable energy during peak times and at night. In this scenario, the control algorithm is economically based since we want to see how the TOU rates align with actual CO\textsubscript{2} emission outputs. The simulation uses emission output calculations from CAISO for each time interval as a sum of all the powerplant CO\textsubscript{2} emissions (imports, natural gas, biogas, biomass, geothermal, coal) \textsubscript{m}TON\textsubscript{CO\textsubscript{2}} / hour. The CO\textsubscript{2} emissions output is divided by the amount of power produced (solar, wind, geothermal, biomass, biogas, small hydro, grid batteries, large hydro, imports, nuclear, coal ) in MW, which gives us an emissions rate of (TON\textsubscript{CO\textsubscript{2}} / hour) / W. This is multiplied with our 15-minute data kW, and a multiplier. The multiplier of $1/ 4000$ to convert kW into W and to address for the four 15 minute periods in an hour. This gives us an estimate of the amount of CO\textsubscript{2} emissions in \textsubscript{m}TON\textsubscript{CO\textsubscript{2}} for every 15 minutes that is summed together to give us the total for the entire period. This method is similar to the one used in \cite{garrido2021dynamic}. When the grid does not pull power from the grid or is sending power, the CO\textsubscript{2} emissions are assumed to be zero since we are using our solar energy.

\section{Simulation in OpenModelica}

OpenModelica is an open-source implementation of the Modelica programming language \cite{OpenModelica}. Modelica is a programming language that is designed for dynamic systems simulation \cite{ModelicaLanguage}. OMEdit is the GUI interface for OpenModelica, allowing the user to draw a system for simulation \cite{OMEdit}. The microgrid scenarios are simulated in OpenModelica using the Modelica buildings library. Lawrence Berkeley National Laboratory created the Modelica buildings library for building and district energy and control systems \cite{ModelicaBuildingsLibrary}. However, its capability for energy storage systems, bi-directional inverter, solar, and HVAC modeling make it ideal for a microgrid simulation setup. This allows us to create scenarios that do not currently exist in our microgrid, like running a month with solar with the same load, or running the BESS control algorithm for different electric rates. The power circuits are three-phase balanced circuits. The simulation of our case study microgrid is the grid-connected to the building netload. The model's net load is broken down into solar power, HVAC loads, regular building loads, electric vehicle chargers, and the BESS as shown in Figure \ref{fig:powersystemsetupfull} .

\section{Results}

The charging setup is modified in OpenModelica for different layouts and scenarios. The scenarios are described in Table \ref{tab:scenarios}. Scenarios 1 through 4 best represent a more typical setup at most EV charging stations. Scenarios 5 through 8 utilize the peak shaving abilities of a large BESS to mitigate the impacts on demand and emissions of EV charging, especially Level 3 charging. Scenarios 1 and 5 show a base case where only solar or solar and ABS are installed at a building. This is to control the experience and compare it with the other scenarios to show the impact of EV charging. Scenarios 2 and 6 would be considered the more typical EV charging setup. Most commercial centers mostly use Level 2 charging, which is relatively cheap and simple to install and does not have too much of a major impact. Scenarios 3,4,7,8 add one 50 kW charger to the setup. This represents the rapid adoption of fast charging and its impacts on commercial buildings. Each scenario is run independently of one other, and the power outputs of the different components in the simulation are shown in Figure \ref{fig:scenariospoweroutputboxplot}. Each scenario’s power pulled from the grid is juxtaposed in Figure \ref{fig:netloadscenariocomparisonsummer}. Theaverage of daily CO\textsubscript{2} emissions from each scenario is shown in Figure \ref{fig:emissionsscenariocomparison}. The emissions and electric price amounts of each scenario are shown in Table \ref{tab:emissions}.

\section{Conclusion}

Electric vehicle charging will have a significant impact on the electric costs and emission levels of a microgrid. Level 2 charging had a relatively minimal effect on costs, with a 60 to 90\% increase in electricity costs, which is not much considering that four Level 2 chargers were used. However, just one Level 3 EV charger can cause double to quadruple electric costs. Level 2 chargers have a very small impact on demand charges even when all four chargers are running since the 7.2 kilowatts of each EV charger is much less, and each has a max peak relative to the system. However, the 50 kW peaks created by the Level 3 charger nearly eclipse the demand for the HVAC units, and both used in unison can double the maximum peak and the demand costs. This happens mostly at noon when HVACs and EVs run simultaneously. Energy chargesboth with and without the BESS are similar, albeit slightly higher with BESS. This was expected since BESS does not reduce energy costs, only demand charges with the flat rate used by the university’s utility company. The costs of Level 2 charging is significantly easier to recover compared to Level 3 charging. The difficulty is that just one charging event that aligns with the other loads can easily double the price of that month’s electrical bill. Implementing a Level 3 charging control system must prohibit users from utilizing fast charging at peak hours when charging one vehicle can cause major costs to the provider. Aside from the major cost differences, locally produced solar power combined with EV charging has a huge potential to reduce CO\textsubscript{2} emissions from transportation. Even when utilizing both Level 2 and3 chargers and no BESS, there’s only a 42\% increase of carbon dioxide emissions compared to no EV charging at all, increasing volume from 21 tons of CO\textsubscript{2} to 30 tons of CO\textsubscript{2}. The X amount of vehicle trips mitigates this slight increase in CO\textsubscript{2} if combustion engine vehicles were used instead.

\section{Future Works}

Future papers will investigate different more advanced control strategies to further decrease electric costs and CO\textsubscript{2} by preventing users from charging during high peak times, utilize the clean energy produced by the solar panels, and only pull power from the grid during low CO\textsubscript{2}