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Microgrid Deployments in the US Performance Data from the Anaheim Transportation Network Microgrid

Bryan Lee[1], Aditya Kushwah[2], Lais Caldeira[3]
1 CALSTART, blee@calstart.org
2 CALSTART, akushwah@calstart.org
3 CALSTART, lcaldeira@calstart.org

Executive Summary

The battery electric bus industry has experienced rapid growth, yet the deployment of these vehicles introduces unique infrastructure risks and challenges. Battery electric buses are reliant on grid power to charge. This reliance on the grid leaves transit fleets vulnerable to being disabled in the event of a prolonged grid outage or failure. To mitigate this risk, transit agencies can address this problem by deploying microgrids and distributed generation assets that can disconnect from the electrical grid and produce power in the event of a grid outage. Anaheim Transportation Network (ATN), a transit agency in Anaheim, California, has deployed a microgrid to power its fleet of battery electric buses. CALSTART is collecting and analyzing performance data from the ATN microgrid to assess its operational effectiveness. The paper discusses the detailed operational performance of the ATN microgrid, evaluating its reliability, efficiency, and contribution to fleet resiliency.

Keywords: Heavy Duty Electric Vehicle and Buses, Charging Business Model, Smart Grid Integration and Grid Management, Energy Storage System, Energy Management

1. Introduction

The transit industry has undergone a major shift towards electrification and zero emission drivetrains. As of September 2023, there were 6,147 zero emission buses (ZEB)s that were funded, ordered, or deployed in the United States [1]. While ZEBs still represent a relatively small fraction of the overall national transit bus fleet, adoption is accelerating in all regions, reflecting a growing commitment to decarbonizing public transportation systems. This transition has been driven by a combination of factors, including the expanded availability of federal and state funding programs, regulatory mandates that require the adoption of zero-emission technologies, and rapid advancements in vehicle and battery technologies. These developments have significantly lowered the barriers to transit agencies seeking to electrify their fleets, enabling broader participation in clean transportation.

Despite the momentum behind transit electrification, the widespread deployment of BEBs introduces several operational and technical challenges, particularly in the areas of charging and refueling infrastructure and proper vehicle-to-grid integration. BEBs require high-power charging and draw substantial amounts of electricity during the charging process. This elevated energy demand can place significant stress on existing utility infrastructure, especially in regions where grid capacity is already constrained. In many cases, limitations in available electrical capacity restrict the number of BEBs a fleet can deploy and operate effectively. Increasing power capacity at a new or existing facility is not a straightforward task as utility infrastructure upgrades are complex, costly, and time-consuming. Expanding site capacity typically involves a multifaceted process that includes upgrading distribution transformers, reinforcing transmission lines, enhancing substations, and coordinating with multiple utility stakeholders. These upgrades often require extensive permitting, engineering studies, capital investment, and sometimes years of lead time, factors that can significantly delay fleet electrification timelines.[2] Additionally, in some urban areas, physical space constraints, aging infrastructure, and competing demands from other sectors (such as commercial and residential electrification) further complicated efforts to scale up available grid capacity at site. As a result, transit agencies encounter struggles in planning for vehicle procurement, charging needs, and looking for long-term solutions such as exploring decentralized energy solutions such as microgrids to ensure reliable and scalable operations.

Another critical concern is resiliency. BEBs rely directly on the electric grid as their sole source of energy for charging, making them vulnerable to service disruptions during power outages. Although the U.S. grid is generally reliable, the gird vulnerability is increasing due to disruption from extreme natural events such as wildfires, floods, and other natural disasters. A prolonged outage can halt transit operations, with serious implications for mobility, access to essential services, and emergency response. In addition to serving daily commuters, transit agencies often support evacuation and emergency operations, making resiliency a key operational priority. Given these challenges, transit agencies are now exploring innovative solutions such as microgrids and distributed energy resources (DERs) to improve energy resilience and mitigate grid dependency. Among these, microgrids are often coupled with on-site battery energy storage systems (BESS) which have emerged as one of the most prominent and practical approaches to overcoming infrastructure and resiliency barriers in the fleet electrification. Microgrid is a localized energy system capable of operating independently or in conjunction with the main utility grid. When integrated with renewable generation (such as solar PV) and BESS, microgrids can not only reduce peak demand and utility dependence but also provide backup power during outages, economic benefits, enhance load management, and support the scalability of BEBs deployments to support fleet electrification goals.

A leading example of microgrid implementation in the public transit sector is the system deployed by Anaheim Transportation Network (ATN), designed to enhance fleet resiliency, support BEBs adoption, and reduce operating costs using DER. ATN is the designated public transit provider for the City of Anaheim and has operated the Anaheim Resort Transportation (ART) service since 2002 with functional 21 routes serving more than 70 stops across Anaheim and Orange County. Today, ATN transports over 9.7 million passengers annually using a fleet of 82 clean-fuel buses, and it is actively transitioning to a 100% battery electric fleet by 2027. To support this transition and address the infrastructure challenges of large-scale BEB deployment, ATN has implemented a state-of-the-art microgrid with battery energy storage at its new operations and maintenance facility, "The Charge," located on Claudina Street. Funded through the California Energy Commission's (CEC) Clean Transportation Program, the microgrid includes 544.68 kW of solar photovoltaic (PV) generation and 2.57 MWh of BESS capacity to meet the changing demands of the BEB fleet. Designed for both economic efficiency and operational resiliency, the system reduces peak grid demand, lowers utility costs, and can provide backup power during outages through islanding functionality. It also increases the proportion of renewable energy used in transit operations, ultimately contributing to the reduction of greenhouse gas (GHG) emissions.

CALSTART has played a central role in monitoring and evaluating the operational performance of the ATN microgrid. As part of this effort, CALSTART is conducting ongoing data collection and analysis to assess the system's functionality under both normal ("blue sky") and outage ("black sky") conditions. Performance data is collected from multiple integrated platforms, including Omega, GPM, and Powerhub, capturing key parameters such as energy generation, consumption, load balancing, battery charging and discharging behavior, and real-world vehicle charging patterns. This data-driven approach provides a comprehensive view of the system's efficiency, resiliency, and impact on transit operations. A detailed overview of the data collection methods and parameters are discussed in Section 4: Microgrid Data Collection.

2. Microgrids a Resiliency Solution

As transit electrification expands, the shift has begun from simply enabling charging infrastructure to ensuring its reliability and flexibility under a variety of operating conditions. In this evolving landscape, microgrids have gained traction not just as backup systems, but as strategic assets that enhance grid interaction, optimize energy use, and safeguard transit operations from future uncertainty. Unlike traditional grid-tied solutions, microgrids provide the technical autonomy and operational control required to support transit agencies aiming for both sustainability and resiliency. Microgrids are local grids that use DERs to provide power to a specific campus or locality. Microgrids are unique in that they can disconnect from the utility grid and self-generate local power for the loads included in the microgrid. The energy portfolio typically includes assets such as solar panels, BESS, and a controller which acts as a brain of overall system and decides when to disconnect from the grid and determines which generation assets are used to produce power as shown in Fig. 1. [3]

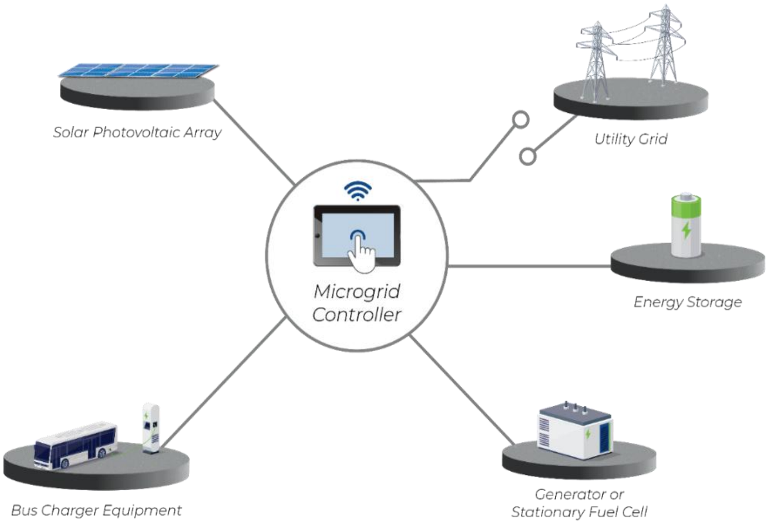


Figure 1. Example Microgrid Diagram [3]

Microgrids can operate in two modes. The first is under blue sky conditions, which occurs when the grid is operating normally. Under blue sky conditions, the microgrid will operate in parallel with the utility grid to provide grid services such as peak shaving, load shifting, and power exporting to grid. The second is under black sky conditions, which occur when there is a grid outage. Under black sky conditions, the microgrid islands from the utility grid and self-generate electricity to power the local load to provide gird resiliency.

2.1 Limitations of Other Resiliency Strategy

One emerging method to mitigate localized grid outages is to use alternative charging sites such as public charging infrastructure. If a transit depot experiences a power outage, a fleet may attempt to reroute vehicles to compatible public DC fast chargers. This approach depends on interoperability between the chargers and fleet vehicles with physical compatibility with the proper bus dimensions, and agreements with local governments to access municipal infrastructure during emergencies. However, this strategy has several limitations. First, most existing public chargers are Level 2 (up to 100 kW) and designed mostly for light-duty or medium-duty fast charging. They are usually not capable of delivering the power needed for heavy-duty transit buses (GVWR above 33,001 pounds). Additionally, this approach only protects against localized outages. In the event of a regional blackout, these same public chargers would also likely lose power, rendering this strategy ineffective. Another resiliency option is to produce power on-site using fossil-fueled generators. These units can supply power during blackouts, but they come with substantial drawbacks. Generators are based on fossil fuel such as diesel or natural gas, resulting in GHG emissions and harmful air pollutants such as nitrogen oxides and particulate matter. Due to their environmental impact, many jurisdictions impose strict operational limits. For instance, in some parts of California, generators are restricted to only operating 200 hours/year. This limitation means that the asset may remain idle for long periods and may become a sunk cost if no outages occur. Additionally, the low utilization of backup generators can lead to mechanical issues or startup failures during critical moments, particularly if the generator is the fleet’s sole source of backup power.

2.2 Microgrids as a Comprehensive Resiliency Strategy

Given the shortcomings of both public charging and fossil fuel-based generators, microgrids have emerged as a robust and scalable solution for transit electrification resiliency. A microgrid is a localized energy system that can operate in tandem with or independently from the utility grid. It integrates DERs such as PV systems, BESS, and in some cases, stationary fuel cell backup generators. One of the key benefits of a microgrid is its ability to island from the main utility during a grid outage and continue to power essential operations. This is made possible through the inclusion of a transfer switch and a microgrid controller, which determines when to disconnect from the grid and how to allocate energy resources. By integrating multiple DERs, microgrids improve resiliency through redundancy. For instance, if one energy resource becomes unavailable, another can compensate. The presence of renewables such as solar PV and storage systems also significantly reduces emissions compared to diesel generators.

2.3 Operational Benefits in Blue Sky Conditions

Microgrids offer more than just emergency backup power. During blue sky conditions microgrids can deliver financial and operational benefits through energy management. Onsite DERs can be used to generate clean electricity and reduce the amount of energy drawn from the utility, lowering overall energy costs. Storage systems allow fleets to engage in load shifting, storing energy during off-peak periods when prices are low and discharged during peak hours when electricity is more expensive. This helps minimize time-of-use costs. Microgrids can also provide peak shaving, where batteries are used to supply energy during short bursts of high demand. Since utilities often charge customers based on their maximum demand in a billing cycle, reducing these peaks can significantly cut operating/charging costs. Moreover, microgrids can offer demand response capabilities, generating onsite power when the grid is stressed and thereby reducing strain on utility infrastructure. These grid services increase asset utilization, create potential revenue streams, and improve the economic feasibility of the microgrid.

2.4 Microgrid Types

The specific design and classification of microgrids can significantly influence their operational flexibility, ownership models, and regulatory obligations. This distinction is particularly important when evaluating how microgrids are integrated into transit operations. At a broader level, microgrids are typically classified into two categories: behind-the-meter (BTM) and front-of-the-meter (FTM). Each operates under a distinct mechanism, as illustrated in Fig. 2.

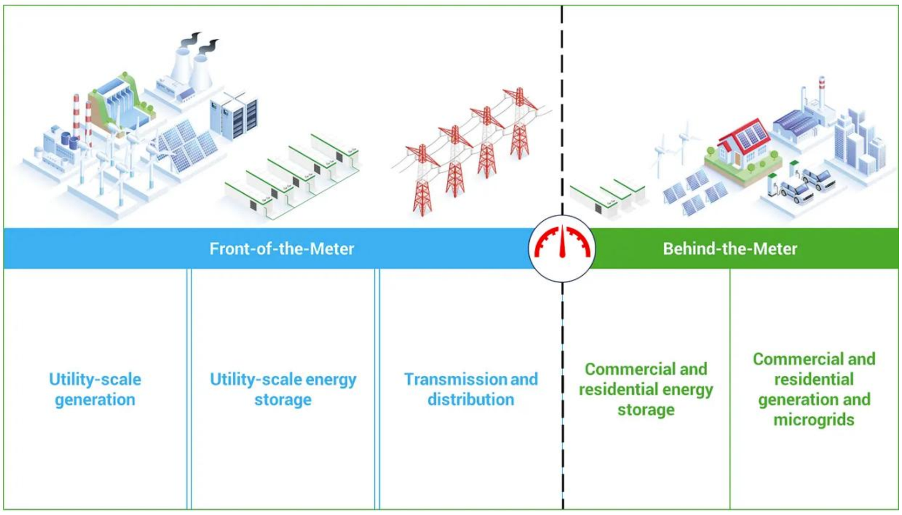


Figure 2. Example of FTM vs BTM microgrids [4]

- **BTM microgrids:** These systems are installed on the customer's side of the utility meter. They primarily serve the energy needs of the individual facility, allowing on-site energy generation (e.g., rooftop solar panels) and storage (e.g., battery systems). BTM systems can reduce energy costs, enhance resilience during outages, and provide greater control over energy usage.

- **FTM microgrids:** These systems are connected to the utility side of the meter and feed electricity directly into the grid. They are typically larger in scale, such as utility-scale solar farms or wind turbines, and are used to supply power to multiple customers. FTM systems play a crucial role in grid stability and large-scale energy distribution.

BTM systems are particularly well-suited for transit fleets, offering tailored energy independence and ensuring operational continuity for charging infrastructure. Regardless of the system type, deploying a microgrid involves navigating a complex landscape of regulatory and utility interconnection requirements. Typically situated on the user's property, BTM microgrids in California benefit from an established framework of regulations, utility tariffs, and interconnection processes, particularly shaped by the implementation of Senate Bill 1339. Enacted in 2018, Senate Bill 1339 directed the California Public Utilities Commission (CPUC), California Independent System Operator (CAISO), and CEC to collaborate on developing policies to support microgrid deployment. Furthermore, regulatory agencies have taken additional steps to streamline microgrid integration through supportive policies and incentives, which are discussed in more detail in Section 6.

3. Anaheim Transportation Network Microgrid

As mentioned above, ATN transportation microgrid, is designed to enhance energy resiliency, lower operating costs, and improve the renewable content of the agency's power supply. It features a solar PV system installed in a carport canopy configuration above the bus parking area. This carport-mounted solar system generates renewable electricity while providing shading for vehicles, which helps reduce the HVAC load and supports the longevity of BEBs on board battery degradation. The detailed specifications of the microgrid are illustrated in Table 1. The project includes all required electrical equipment to connect to the utility grid, ensuring seamless integration with Anaheim Public Utilities (APU). The microgrid's point of interconnection is configured at 480/277V through a 3-phase, 4-wire setup, with a current rating of 4000A. A new electrical service and utility meter is installed for proper operation, and the system ties into an existing switchboard mounted on an exterior concrete pad. The PV array spans a surface area of approximately 28,584 square feet, maximizing the site's usable rooftop space.

Table 1 Technical specification of ATN Microgrid

Component	Specification
Solar PV Modules	1,224 REC Solar REC445AA 72 modules
PV Array Configuration	Canopy-mounted, 5° tilt, 164.5° azimuth
PV System Capacity (Dc)	545.00 kW
PV System Capacity (Ac)	450.00 kW
Inverters	9 x CPS America SCAS60KT-DL0US-480
CEC System Size (Ac)	504.32 kW
DC:AC Ratio	1:21
System Voltage (Dc)	1000 V
System Voltage (Ac)	277/480 V
Bess Capacity (Power)	1,400 kW
Bess Capacity (Energy)	2,569 kWh
Configuration	3PH, 4W
Controller	Tesla Site Controller
PV Area	28,584 sq ft

The system complies with a wide range of regulatory codes and standards, including the 2019 California Electrical Code, California Building Code (CBC), CALOSHA, NFPA 70, and relevant Orange County ordinances. The engineering design also accounts for local zoning, seismic (Class D), and wind (Class B) classifications.

As mentioned, ATN is actively transitioning to a fully zero-emission fleet by replacing its existing fossil fuel and CNG-powered buses with BEBs. To support this transition, ATN has invested in charging infrastructure integrated with a microgrid system located at its main maintenance facility, as shown in Fig.

3. The system combines a 545 kW DC solar array with a Tesla MegaPack BESS rated at 1,400 kW/2,569 kWh. Controlled by a Tesla Site Controller and fully grid-connected. The battery plays a critical role in managing demand response and mitigating peak utility load during high-cost periods between 4 PM and 9 PM. By supplying stored solar energy during these hours, the BESS significantly reduces demand charges. Notably, the battery is configured to charge exclusively from onsite solar generation rather than grid electricity, reinforcing ATN's commitment to clean energy integration. This strategy aligns with ATN's zero-emission goals and enhances the economic value of its renewable energy investment.

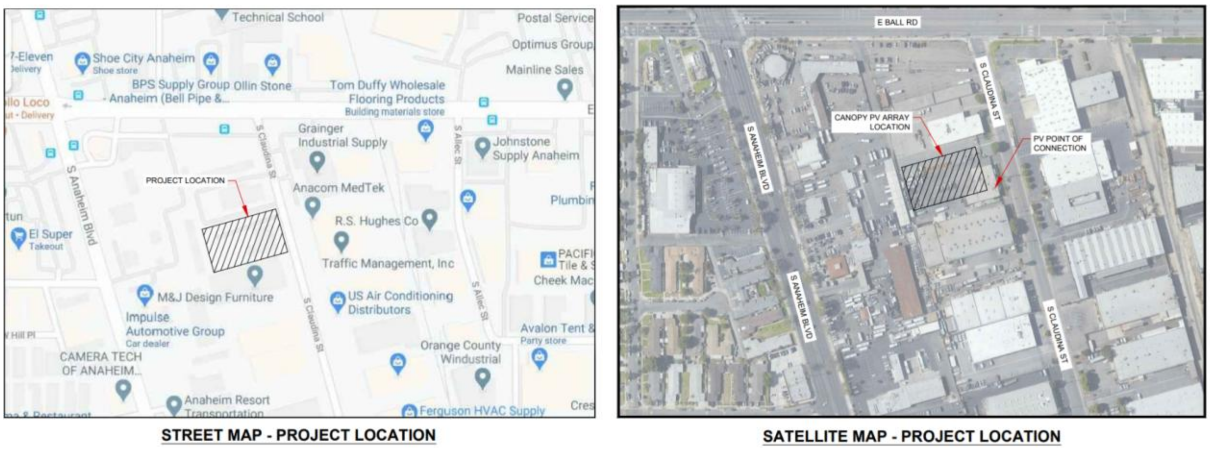


Figure 3. ATN Microgrid Project Location

4. Infrastructure Data Collection

To evaluate the performance of ATN's overall infrastructure, which includes chargers as well as a microgrid composed of solar PV and BESS, CALSTART applied a structured methodology for data collection and analysis using high-resolution interval data from multiple subsystems. While the ATN microgrid was deployed in mid-June 2024, the initial commissioning phase involved minor equipment adjustments and site-level maintenance. To ensure an accurate assessment, this paper only focuses on performance data from September 2024 to March 2025. Charger's operational data was primarily sourced from the Omega (BP Pulse data collection portal) system, which collects each charger uptime, downtime, and energy transfer data in 15-minute intervals. This data enables a granular understanding of how BEBs are being powered and when critical charging events occur. Fig. 4 presents the total number of charging sessions in 15-minute intervals for the analyzed period.

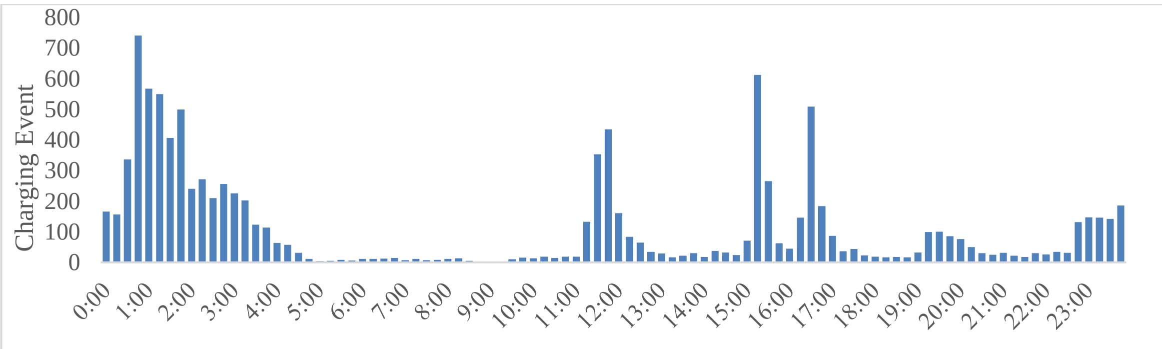


Figure 4. Total number of charging sessions for every 15 minutes interval (Sep/2024 – Mar/2025)

In parallel, solar PV generation data was captured in 15-minute intervals to track the renewable energy contribution and its alignment with fleet charging demand. Battery performance metrics, including charge/discharge cycles and energy throughput, were recorded via Tesla's Powerhub platform. These data streams were further complemented by Tesla's microgrid controller outputs, which track integrated system behavior and coordinated energy dispatch. All datasets were processed and visualized in a Power BI dashboard developed to assess temporal load patterns, energy source allocation, and system responsiveness.

Plotting all this information in a structured dashboard layout also allowed CALSTART to identify minor tracking and reporting issues, which were subsequently investigated and addressed by the microgrid operator. This approach provided assurance that the information analyzed was accurate and reliable, reinforcing the validity of the performance and benefit assessments conducted throughout the project. Fig. 5 provides an example, showing some screenshots from various pages of the dashboard.

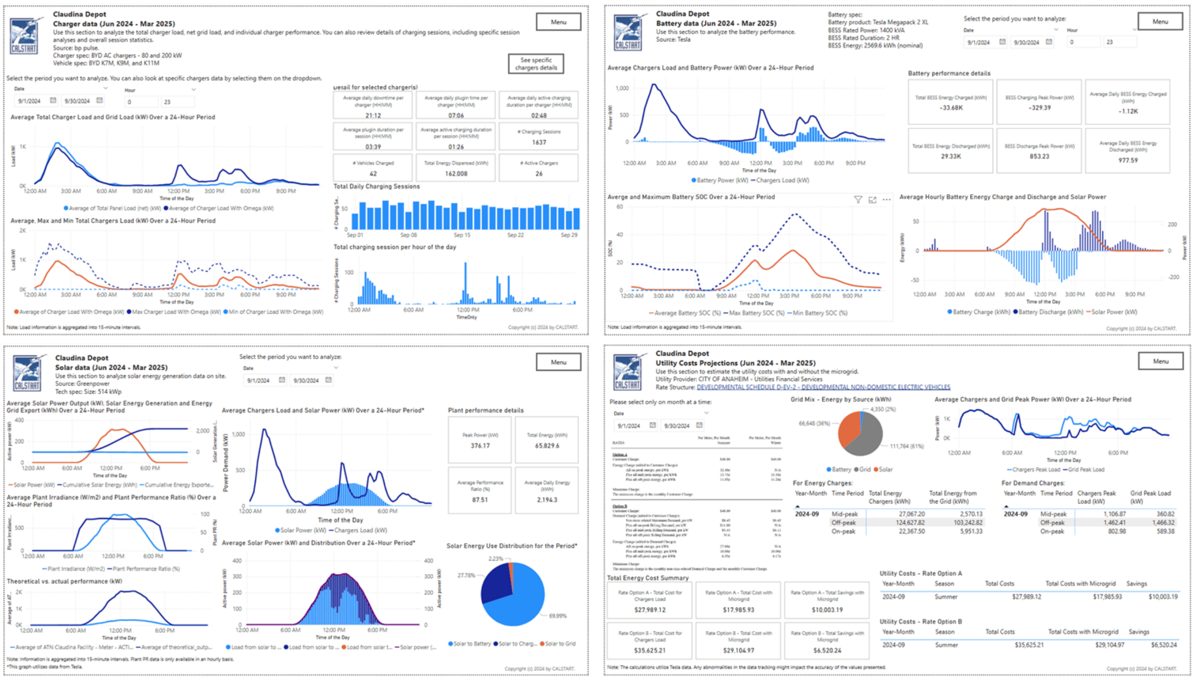


Figure 5. Overview of the Power BI Dashboard

Using performance data recorded at 15-minute intervals from the different sources, Fig.6 shows the system’s average behavior over a 24-hour period under blue sky conditions. The data reveals three main charging periods: overnight from 11:00 PM to 5:00 AM, around midday, and in the late afternoon between 3:00 PM and 6:00 PM.

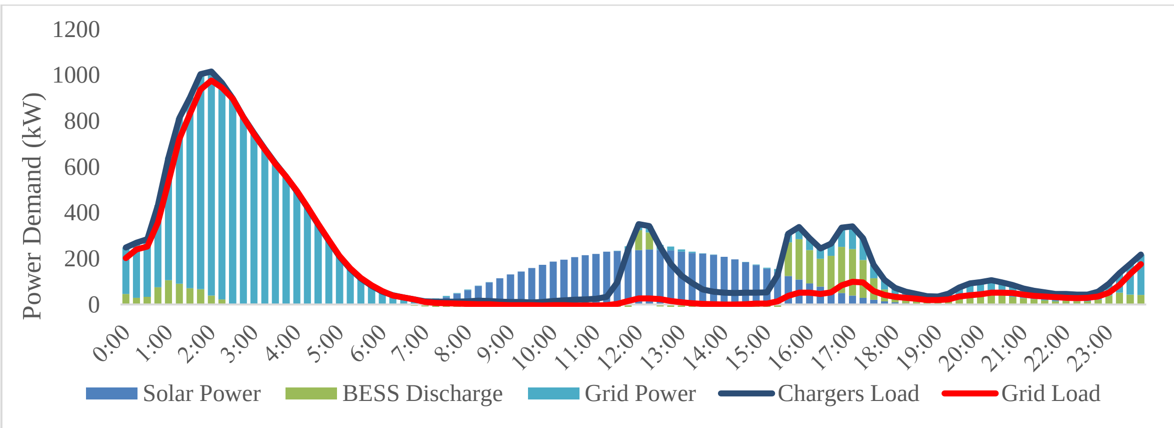


Figure 6. Load Profile and Microgrid Behavior Under Blue Sky Conditions

The dark blue bars represent solar power generation, which typically occurs between 8:00 AM and 5:00 PM and peaks around noon, coinciding with one of the main charging periods. When solar output exceeds the immediate energy demand of the chargers, the surplus is stored in the BESS. During the midday peak, when charging demand surpasses the available solar generation, the BESS begins discharging to supplement the load.

As solar production gradually declines in the late afternoon, the BESS continues to discharge, with output peaking between 4:00 PM and 6:00 PM. This period overlaps with the utility's on-peak hours, when electricity prices and grid stress are typically high. By discharging strategically during these hours, the system reduces dependence on grid-supplied power. Overnight, between 1:00 AM and 5:00 AM, energy is primarily drawn from the grid, taking advantage of lower off-peak rates while solar power is unavailable. The red and dark blue lines on Fig. 6 provides a comparison of the grid load with (red line) and without the microgrid in operation (dark blue line). In addition, as was already mentioned, the BESS system was programmed to be charged only by solar power, which can be observed on Fig. 7. Utilizing a charging management system can enhance operational efficiency by ensuring the BESS is discharged strategically throughout the day.

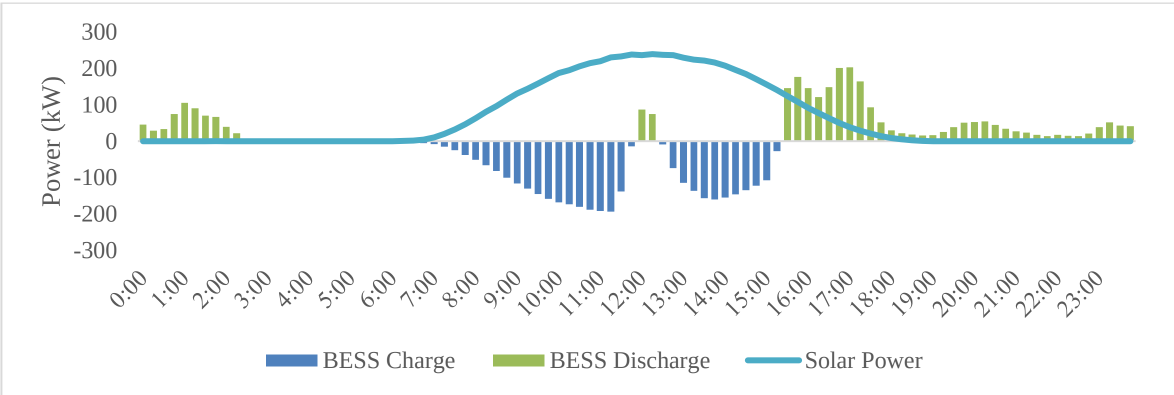


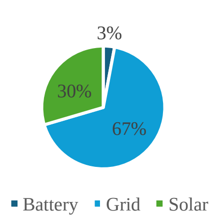
Figure 7. BESS Charging and Discharging Profile

During the analyzed period, no blackout events occurred, which limited CALSTART's ability to evaluate the microgrid's islanding capability and its performance under emergency conditions. However, CALSTART will continue collecting data for over a full year and is working with ATN and other project partners to schedule a planned outage to assess system functionality under black sky conditions in the near future. The following section presents data on the actual performance and benefits of the microgrid during normal operating conditions.

5. Microgrid Performance and Benefits

Given the microgrid performance outlined in the previous section, this section highlights the system's operational benefits over a seven-month period, from September 2024 to March 2025. During this time, ATN performed over 10,500 charging sessions, which delivered more than one gigawatt-hours of energy.

The solar PV system produced a total of 335,801 kWh and exported 5,117 kWh back to the grid. The pie chart on Fig. 8 shows that, of the total energy required to charge the fleet, 30% was supplied directly by solar generation, 3% was discharged from the BESS, and the remaining 67% was drawn from the grid. This demonstrates the microgrid's ability to reduce reliance on the grid and optimize the use of renewable and stored energy resources.



Year-Month	Season	Total Costs Without Microgrid	Total Costs with Microgrid	Savings	% Savings
2024-09	Summer	$27,989.12	$17,985.93	$10,003.19	36%
2024-10	Summer	$26,217.89	$18,445.69	$7,772.20	30%
2024-11	Winter	$17,183.68	$12,619.07	$4,564.61	27%
2024-12	Winter	$18,822.93	$15,723.14	$3,099.79	16%
2025-01	Winter	$19,246.09	$15,080.30	$4,165.79	22%
2025-02	Winter	$15,895.50	$11,367.65	$4,527.84	28%

Figure 8. Energy mix and utility cost saving with and without microgrid

In economic terms, the microgrid also enabled significant savings on the utility bill, as shown on the summary table in Fig. 8. On average, the system reduced utility costs by 26% over the period analyzed. Savings reached as high as 36% during the summer months when solar generation was at its peak, and were comparatively lower, around 16%, during the winter months when solar availability naturally declined. It is important to note that the economic benefits of a microgrid will vary depending on the utility rate structure at each location, particularly the timing and pricing of on-peak and mid-peak periods. ATN's applicable rate structure is City of Anaheim's Developmental Schedule D-EV-2, with a customer fixed charge of $40 per month, an on-peak energy charge of $0.324/kWh during summer months, and no demand charge. [5]

In addition to economic and environmental advantages, the microgrid contributes significantly to grid resiliency by reducing peak demand on the utility grid. As shown in Fig. 9, the peak load drawn from the grid was consistently lower across all months when the microgrid was operational, compared to scenarios without it. This reduction is especially critical during summer months and on-peak and mid-peak hours, when system-wide demand is typically higher. By managing and shifting loads through solar generation and battery storage, the microgrid helps alleviate pressure on the broader electrical grid, reducing the risk of overloads and contributing to overall system stability.

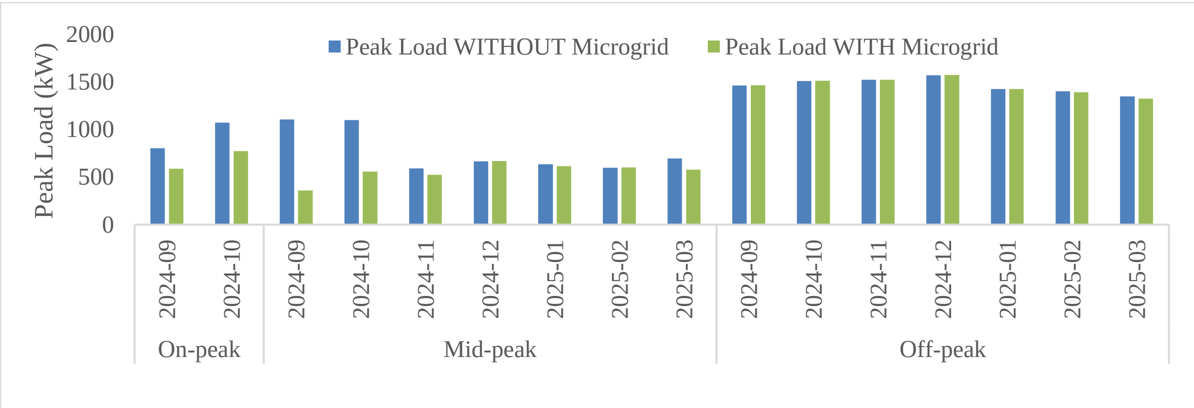


Figure 9. Peak Load (kW)

Finally, using the U.S. EPA's emissions calculator [6], that accounts for the local energy mix based on the facility zip code. The solar energy generated by the microgrid was translated into a measurable reduction in GHG emissions. As presented in Table 2, the total emissions avoided over the analyzed period reflect the direct environmental benefit of replacing grid electricity with clean, renewable solar power. This further reinforces the role of microgrids not only in supporting fleet electrification and reducing operational costs, but also in advancing broader sustainability and climate goals.

Table 2. Emissions Reduction (kg) - Scope 2 and 3

CO_2	CH_4	N_2O	CO_2e	NO_X	SO_2
69,366	3.971	0.476	69,611	48.3	3.2

6. Policy and Regulatory Support: The Role of the CPUC, CEC and CAISO

The advancement of microgrids, particularly transportation microgrid systems, relies not only on technical innovation but also on the strength of the regulatory and policy environment in which they operate. From permitting and utility interconnection to long-term cost recovery and grid coordination, policy frameworks impact successful implementation of such microgrids. In the context of public transit, where energy reliability and cost control are essential, these regulatory dimensions can either empower or restrict the deployment of these distributed energy resources. Microgrids designed to support ATN, including the transportation microgrid discussed in this paper, fall under the jurisdiction of the CPUC and are supported by the CEC.

6.1 Policy Landscape for Behind-the-Meter Microgrids

BTM microgrids have become increasingly relevant for transit agencies seeking to enhance operational resilience and reduce energy costs while supporting zero-emission goals. However, their deployment often faces regulatory complexities that can hinder timely implementation. Common challenges include permitting and interconnection delays, lack of standardization across utility service areas, and ambiguous cost and allocation structures. Despite these hurdles, state-level climate mandates and energy policy reforms for DERs have helped advance BTM microgrid adoption. Transit-focused agencies now benefit from dedicated funding programs, such as those administered by the CEC and increasing regulatory momentum provided by regulators such as the CPUC help transit agencies to prioritize clean energy infrastructure for critical public services. For transit fleets, BTM microgrids offer significant operational value. When integrated with solar PV systems and BESS, these systems enable fleets to self-generate electricity, shift loads away from peak pricing hours, and reduce grid demand charges, improving both resilience and cost control. The regulatory framework, however, defines the boundaries of what is permissible and financially viable, influencing everything from the ability to island during outages to interconnection approval timelines. Understanding and navigating these frameworks is therefore critical to successful microgrid planning and execution.

As part of this paper, CALSTART interviewed CPUC's Staff to better understand the regulatory priorities and challenges surrounding microgrid implementation in California. The CPUC plays a foundational role in shaping the regulatory environment that governs microgrid deployment across the state. As the agency responsible for regulating investor-owned utilities and overseeing distributed energy policies, CPUC has advanced multiple initiatives that support the integration of clean energy infrastructure, especially for critical facilities like transit depots and public sector buildings. Through SB 1339, the CPUC was tasked with developing a comprehensive framework to accelerate the commercialization of microgrids. This led to a series of regulatory proceedings aimed at streamlining permitting, standardizing interconnection, and clarifying cost recovery structures. The insights presented in this section are informed by discussions with the CPUC's Regulatory Analyst, highlighting California's leadership in advancing a resilient, flexible, and accessible energy system, particularly through the implementation of SB 1339. Enacted in 2018, SB 1339 directed the CPUC, CEC, and CAISO to collaborate on policies related to microgrids. This led to the formal initiation of Rulemaking R.19-09-009 to develop a policy framework for microgrid commercialization, laying the foundation for the Microgrid Incentive Program.

Track 1 of this rulemaking, through Decision D.20-06-017, required the creation of a streamlined, template-based application process for specific BTM microgrid projects. It aimed to remove barriers such as permitting challenges and sizing limits, enable local programs, and design dedicated rates and tariffs for these systems. Track 2, via Decision D.20-06-017, introduced an interim approach to reduce emissions from backup generation during transmission outages and initiated a transition to clean temporary generation starting in 2022. Track 3, through Decision D.21-07-011, suspended the capacity reservation component of standby charges for eligible microgrid technologies. Track 4 was launched on August 17, 2021, in response to Governor Newsom's July 30, 2021, State of Emergency Proclamation addressing the worsening impacts of climate change. This track included an expedited Phase 1 and a broader Phase 2. These proceedings demonstrate California's recognition of microgrids as critical tools in the transition to a clean energy future. Microgrids can enhance customer reliability, improve energy management, function as aggregated resources for grid operators, and support state goals for integrating distributed energy resources.

Looking ahead, Singh emphasized that CPUC will continue to play a central role in enabling the widespread adoption of BTM microgrids by shaping interconnection policy, modernizing utility frameworks, and aligning incentives with long-term climate and equity goals. CPUC has also overseen updates to Rule 21, California's interconnection tariff, which outlines the technical and procedural requirements for DER to safely connect to the grid. Rule 21 addresses key aspects such as voltage control, islanding, and protection coordination. Although recent updates have improved approval timelines and interconnection transparency, challenges remain in implementation across diverse utility service territories.

In addition to regulatory reforms, CPUC administers critical incentive programs such as the Self-Generation Incentive Program (SGIP) and the Microgrid Incentive Program (MIP), which provide financial support for microgrid projects targeting public sector entities, low-income communities, and fire-threat areas. These programs aim to overcome high capital costs and improve deployment equity statewide. It was noted during the interview that these policy levers are not only about enabling microgrids but ensuring that they are part of a larger, resilient, and inclusive clean energy strategy. The discussion also emphasized the importance of regulatory certainty, utility coordination, and the need for continued stakeholder engagement to ensure that microgrids can scale effectively within a supportive and standardized policy framework.

From the perspective of the ATN, CPUC's regulatory oversight was especially relevant during the interconnection and permitting process of its BTM microgrid. Navigating Rule 21 requirements and aligning the system's technical configuration with utility safety standards were necessary steps to ensure successful deployment. Support from CPUC-enabled programs also helped reduce permitting barriers, making the integration of solar and BESS systems more economically viable for a public transit agency. CPUC's evolving role reflects a broader shift in state policy, one that supports decentralized energy resilience while maintaining system-wide reliability. Its continued leadership will be critical as more transit fleets and the public seek to replicate successful microgrid models like ATN's. As more transit agencies explore BTM microgrid solutions, ongoing coordination with agencies such as CPUC and investor-owned utilities will remain critical for scalable, equitable, and efficient clean infrastructure deployment

7. Discussion and Conclusion

The performance evaluation of the ATN microgrid offers a compelling case for the integration of BTM and DER systems in public transit operations. The data-driven assessment confirms that when properly designed and deployed, microgrids can serve not only as backup systems but as integral tools for managing energy demand, controlling costs, reducing emissions, and enhancing grid resilience. From a technical perspective, the microgrid consistently demonstrated effective coordination between solar generation, BESS, and grid interaction. One of the most notable findings was the precision with which the BESS was charged exclusively from solar energy and strategically discharged during high-value intervals, primarily between 4:00 PM and 6:00 PM. This targeted discharge aligns closely with the utility's on-peak pricing window and reflects the impact of intelligent charging management systems. These capabilities also offer flexibility in fleet operations, allowing BEBs to operate on rigorous duty cycles without exhausting onboard storage while maintaining operational efficiency.

The system's role in smoothing demand was evident. As shown on Fig. 9, peak grid demand was consistently lower during peak and mid-peak hours across all months from September 2024 to March 2025, even during the winter season. This ability to flatten load profiles helps mitigate the risk of grid overload and allows utilities and ATN to avoid costly and time-intensive infrastructure upgrades. These system-level benefits extend beyond the depot and support broader distribution network stability. During the data collection period, no outage or grid failure events were observed. However, such risks are more likely during summer months when wildfire threats place additional stress on California's grid. Based on the system's solar and BESS performance, the fleet is expected to operate without disruption in the event of future outages. The peak load profiles observed during the evaluation also revealed that the greatest dependence on the utility grid occurred during nighttime off-peak hours, when electricity prices are lowest and solar production is unavailable. This pattern suggests microgrids are well-optimized to balance economic and operational priorities, favoring renewable and stored energy during high-cost periods while utilizing grid energy only when rates are most favorable.

From an economic standpoint, the microgrid consistently delivered cost savings. Monthly utility bills were reduced by an average of 26%, with peak savings reaching 36% during months with strong solar generation, particularly in September and October 2024. Even in lower-solar winter months, savings ranged from 16 to 28%. These reductions were achieved without sacrificing charging reliability or capacity, highlighting the strong return on investment for the system.

Further the solar PV system also helped avoid more than 60 metric tons of CO_2 emissions, in addition to reductions in CH_4, N_2O, NO_x, and SO_2. These outcomes demonstrate the role microgrids can play in supporting decarbonization targets while simultaneously improving operational performance. The broader regulatory and policy context was also essential in enabling project success. Support from the CPUC, including guidance under Rule 21 and incentive programs such as SGIP and MIP, played a key role in facilitating interconnection and reducing financial barriers. However, the deployment experience revealed areas for improvement, particularly related to permitting timelines and cost recovery frameworks, where continued regulatory streamlining will be important to support future scalability. Overall, ATN microgrid provides a model that public agencies can reference as they implement distributed energy solutions to support transportation electrification. As California and other states accelerate the transition to clean public infrastructure, microgrids will play an increasingly important role in delivering systems that are economically sustainable, environmentally responsible, and operationally resilient.

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References

[1] Mike Hynes, Alise Crippen, Kaila Lemons, and Emily Varnell. *Zeroing in on ZEBs: The Advanced Technology Transit Bus Index: A ZEB Inventory Report for the United States and Canada*. CALSTART, 2024. https://calstart.org/zeroing-in-on-zebs-2024/, accessed on 2025-05-01

[2] California Public Utilities Commission (CPUC), *Infrastructure Planning and Investment*, https://www.cpuc.ca.gov/infrastructure/, accessed on 2025-05-01.

[3] Bryan Lee, Aditya Kushwah, and Kristian Jokinen. *Microgrids: Best Practices for Zero-Emission Bus Resiliency*. CALSTART, 2023. https://calstart.org/wp-content/uploads/2023/06/Microgrids-Best-Practices-for-ZEB-Resiliency.pdf, accessed on 2025-05-01.

[4] Power Sonic, *Behind the Meter vs. Front of the Meter*, https://www.power-sonic.com/blog/behind-the-meter-vs-front-of-the-meter/?utm_source=chatgpt.com, accessed on 2025-05-01.

[5] City of Anaheim, *Developmental Non-Domestic Electric Vehicles Rate*, https://www.anaheim.net/DocumentCenter/View/20547/Developmental-Non-Domestic-Electric-Vehicles, accessed on 2025-05-01.

[6] U.S. Environmental Protection Agency (EPA), *Power Profiler*, https://www.epa.gov/egrid/power-profiler#/, accessed on 2025-05-01.

Author Biography

Bryan Lee is a Lead Project Manager at CALSTART. He works on projects related to technology development, infrastructure, and workforce development for the zero-emission bus sector. Bryan's research interests have recently expanded into the zero-emission trucking and marine sectors. Prior to CALSTART, Bryan worked in renewable energy and academia. Bryan has an MA in Strategic Studies from University College Cork, an MS in International Development from Trinity College Dublin, and a BA in Economics & Philosophy from the University of California, Santa Barbara.

Aditya Kushwah is a Technical Project Manager at CALSTART. He investigates the techno-economic feasibility of transitioning to zero emission fleets and develops business cases for fleet decarbonization. Aditya specializes in techno-economic modelling of DERs and microgrids, energy modeling, GHG inventories, and cost-benefit analyses for zero emission fleet transitions. Prior to CALSTART, Aditya worked at the Schatz Energy Research Center and at Terra Motors (an EV manufacturing company based in India and Japan). Aditya holds an MS in Energy Technology and Policy from Cal Poly Humboldt and a BS in Mechanical and Automation Engineering.

Lais Caldeira is a Technical Associate Project Manager at CALSTART. She leverages data analysis and technical expertise to assess and demonstrate the feasibility and performance of zero-emission technologies, helping fleets transition to more sustainable operations and contributing to a cleaner, more sustainable future. Prior to CALSTART, she worked at the National Confederation of Transport in Brazil, where she led research on infrastructure conditions and investment needs. Lais holds a Master of Public Policy from the University of Chicago, an MA in Transportation, and a bachelor's in production engineering from the University of Brasília.