DRAFT DISCUSSION DOCUMENT

Electricity Costs for Battery Electric Bus Operation

Battery electric buses (BEB) are propelled by electricity and require regular charging to replenish their onboard batteries. Currently there are two primary strategies for charging BEBs.

- “Slow charging” and is characterized by drawing electricity at a slower rate over a longer period of time. Slow charging is most commonly accomplished overnight over several hours.
- “Fast charging” involves drawing large amounts of electricity from the grid in short time windows, usually 15 minutes or less. Fast charging is accomplished while the bus is on its regular route and is commonly referred to as “on-route” or “opportunity” charging.

It is important for BEV operators to understand how electricity rates and costs differ between charge strategies, utility service areas, and other factors. This paper will explain rate structuring and the various components of existing electricity rates that apply to transit bus charging. After explaining the rate factors, detailed examples will be provided to demonstrate how those factors influence BEB operational costs. Finally, this paper will outline a few tools BEB operators might use to mitigate electricity costs.

1. Overview of Electricity Rate Structures

Electric rates are generally designed to be based on the cost of service, so the utility can recover the cost to generate electricity, transmit it over long distances, and distribute to end-use customers. California’s electric utilities are also “decoupled” meaning their profits are not tied to energy sales, to encourage conservation and efficient use of the system. Electric utilities lay out their electricity charges in rate schedules, also called tariffs. Rate schedules detail all rates and charges. Rate schedules change infrequently and are tightly regulated. Schedules are available on the website of every utility. Each utility will have schedules for different power requirements and will be segregated into residential and non-residential. The focus of this paper is on non-residential or commercial rates that apply to transit fleets. Customers are placed in an appropriate tariff based on their real or expected electricity demand (highest rate at which the metered site draws from the grid). Many utilities will further segregate tariffs into specific applications.

Electricity charges commonly vary by season and are divided between summer and winter, with summer months being billed 4 to 6 months of the year depending on the utility. Electricity is more heavily used during the summer; it is also more expensive. On most rate schedules applicable to commercial customers, electricity costs change by time of day. This type of rate schedule is called time-of-use (TOU). Rate times will typically be divided into three categories: on-peak (or super-peak), mid-peak (or part-peak or semi-peak), and off-peak. During the summer, on-peak hours are in the afternoon commonly between noon and 6 p.m., mid-peak hours are in the morning and late evening commonly from 8 a.m. to noon and 6 p.m. and 10 p.m., and off-peak hours cover everything else — generally overnight. TOU hours vary among utilities.

Electric utilities typically charge commercial customers in three ways: usage-independent fees (customer charges), usage charges, and demand charges. The total cost of electricity for each billing period is the sum of these costs. Each of these is described in the section below.

a. Usage-independent fees

Usage independent fees are those levied on a recurring basis (daily or monthly). In rate schedules, the fees are assessed as a fixed fee for each electricity meter a customer uses and aren’t directly correlated with energy usage. These fees are associated with costs for monitoring and billing and are often called basic service fees and do not change from month to month.

b. Usage Charges

Usage charges are levied based on how much electricity, in kilowatt-hours (kWh), a customer uses in a billing period (usually a month) and the TOU period the electricity is used. Usage will commonly appear on a schedule as an “energy” charge. It’s charged by the utility in $/kWh (usually $0.05 - $0.25/kWh) and is typically referred to as the commodity cost or generation fee. Electricity usage charges are primarily associated with the cost of producing electricity. Electricity usage rates are higher during on-peak periods cost more than in mid-peak or off-peak periods.

c. Demand Charges

Demand charges are levied based on the maximum amount of electricity a customer draws at once and the TOU period in which the electricity is used. A demand charge, simply, is a fee paid based on the rate at which the customer draws electricity. Demand, also called power, is measured in kilowatts (kW). Demand charges are primarily associated with the cost of delivering electricity. Demand charges are commonly assessed based on the maximum demand during the monthly billing period, but some rates schedules also add additional demand charges based on demand that occurs during the on-peak period or mid-peak period. In all cases, the final bill adds the maximum demand charge to the charges of on-peak and mid-peak demand. In general, demand is metered in 15-minute intervals. That is, the demand is measured as the average kW used in 15 minutes. The following briefly describes the how the demand for each period is determined.

Maximum Demand - The “maximum” demand is determined by the highest demand (rate of electricity draw in kW) during the month regardless of the time of day it occurs.

On-Peak Demand - The “on-*peak”* demand charge is determined by the highest demand that occurs during the “on-peak” demand period.

Mid-Peak Demand - The “mid-peak” demand charge is determined by the highest demand that occurs during the “mid-peak” demand period.

Example A shows that if a customer drew 2000 kW for 15 minutes, their demand would be measured as 2000 kW. But if the customer instead drew 2000 kW for 7.5 minutes (half of the 15-minute interval) and then drew 0 kW for the next 7.5 minutes, the measured demand during that time would average 1000 kW.

$$Example\ A\colon 2000\ kW \times \frac{15\ min}{15\ min} = 2000\ kW\ demand$$

$$Example\ B\colon 2000\ kW \times \frac{7.5\ min}{15\ min} = 1000\ kW\ demand$$

Fifteen-minute metering intervals are standard in the industry, but some utilities have language in their tariffs that gives them the option to meter with shorter intervals in certain cases. If it is possible for a utility to meter at shorter intervals such as five minutes, it could strongly influence demand charges.

More on Demand Charges
Making an analogy to plumbing, it is comparable to how many gallons of water a person draws at any given moment. In a plumbing example, a user could choose to turn the faucet on low and fill a five-gallon bucket over ten minutes (a low demand), or choose to turn the faucet on high and fill the five-gallon bucket in one minute. In both cases, the person drew five-gallons of water, but in the latter case, the rate of flow was much higher.

If the user above wants to fill the bucket in one minute rather than ten minutes, the water utility may need to widen the pipes to the faucet, maintain a higher reserve, and have bigger pumps to deliver the water at the higher rate. Therefore, the water utility may charge the user more to recover the costs of infrastructure and/or reserve needed to deliver the water faster. In both cases the person still has to pay the same amount for the total volume of water used. The total bill for drawing the water faster is higher even though the same amount (5 gallons) of water is drawn.

This analogy applies to electricity use. A demand charge, simply, is a fee paid based on the rate (think: gallons per minute) at which the customer draws electricity. In the case of electricity, the “gallons per minute” is measured in kilowatts (kW). Kilowatts are useful to think of as kWh/h, where kilowatt-hours (kWh) are equivalent in this analogy to gallons — they’re the total volume of electricity delivered — and kWh/h is how many kWh are delivered in a given amount of time. It is useful to think of demand charges as fees assessed for being able to draw a lot of energy in a short amount of time.

2. Total Electricity Costs

The total cost of electricity on a monthly basis is the sum of all fees and charges. All demand charges are additive and any peak demand charge incurred will be added to the maximum demand charge. In this section we describe the basic assumptions we use for these bus charging examples, how the monthly costs are calculated, and how the total electricity cost changes with different charging strategies. For simplicity we will show the calculation for the summer months, but the charging strategy in each example is assumed to remain the same all year and the calculation method would the same with the exception that winter rates are generally lower.

In the following basic examples for slow charging or fast charging, each bus is assumed to travel 4,000 miles per month and use 10,000 kW-hr of electricity per month. The buses are charged on a separate meter from any other loads. For simplicity we use an example of 10 buses and use the same rate tariff to show how charging strategies change the total electricity cost.

a. Slow Charge Buses

For this slow charge bus example, the buses are typically operated during the day and are charged at night for about 4 to 5 hours. Each bus is equipped with an 80 kW charger. As the buses complete their day they are cleaned and prepared for the next day and are plugged in to charge. The first bus is plugged in in the evening and draws 80 kW to charge the bus. As additional buses continue to come in over the next few hours during the late evening each bus that is plugged in adds another 80 kW to the total demand until all buses are plugged in and are charging at the same time. When all 10 buses are charging at the same time the demand at that time is 10 buses x 80 kW = 800 kW. The buses are charged in a manner that 25% of the electricity usage occurs during the mid-peak period and 75% occurs during the off-peak period.

The rates in the Table 1 are for the SDG&E service area with the AL-TOU >500 kW tariff that applies to large utility customers. For this rate schedule there is a meter fee that adds $466 per month to the bill that is not shown in the calculation below. The following table shows the demand costs and usage costs.

Table 1- Slow Charging 10 Buses at the Same Time

Usage Charges	$/kWh		kWh		Total
On-Peak	$0.12	x	0	=	$0
Mid-Peak	$0.11	x	25,000	=	$2,750
Off-Peak	$0.08	x	75,000	=	$6,000
Total Usage Charges					$8,750

Demand Charges	$/kW		kW		Total
Maximum Demand	$22.55	x	800	=	$18,040
On-Peak	$19.19	x	0	=	$0
Mid-Peak	$0.00	x	266	=	$0
Total Demand Charges					$18,040

Monthly Total (Summer)	$26,790

Usage charges are generated simply by multiplying kWh used by the rate during the period of use, as shown in the top portion. The maximum demand, 800 kW, occurs when all buses are being charged at the same time in the late evening and early morning. Since no buses are charged on-peak, there is no demand or energy use during that period. Because there is some amount of charging during mid-peak, there’s a small amount of usage and demand, though there’s no added cost for demand mid-peak. The total bill for this summer example is $26,790 and equates to about $0.67 per mile.

Slow charge fleets can be scaled up with no increase in cost per mile. Using the same scenarios above, two buses will draw 160kW of demand and use 20,000kWh of electricity mid- and off-peak leading to a bill of $5,358 and $0.67/mile ($5,358/8,000miles). Four buses will draw 320kW of demand and use 40,000kWh of electricity leading to a bill of $10,716 and still $0.67/mile ($10,716/16,000miles).

If this fleet were able to manage its charging so that only 5 buses were being charged at the same time the maximum demand would be cut in half to 400 kW[1] (5 chargers x 80 kW = 400 kW) with everything else being the same. The maximum demand charge shown above would be reduced from $18,040 to $9,020. The total monthly bill would be reduced from $26,790 to $17,770. This equates to a cost of about $0.44 per mile. If during the month, the fleet plugged in all buses at the same time just once (for at least 15 minutes) the demand charge would be based on 800 kW and would not be reduced. Changing charge schedule can be done by manually plugging/unplugging the buses or by using management software that can automate and coordinate bus charging. Some vehicles come standard with software to control charging.

---

[1] If the fleet managed the example 10 bus fleet consistently below 500 kW, they would be placed in a lower rate tariff.

The fleet could also lower its usage cost by using the same strategies but moving all charging to the off-peak period. This usage for the mid-peak period at $0.11/kWh would be shifted to the off-peak period with a usage charge of $.08/kWh (25,000 kWh x $.03/kWh lower) = $750 lower cost.

As this example shows, managing the demand even during off-peak and mid-peak periods has a much bigger effect on the electricity cost than when the usage occurs. These examples are scalable for larger fleets and the cost per mile will not change. For a 100 bus fleet, the electricity costs shown above would simply be 10 times higher plus the $466 per month meter fee.

b. Fast Charge Buses

For this fast charge bus example, the 10 buses are typically operated during the day with multiple, short charging events to sustain operation. There are two 500kW chargers on route, located apart from each other and on their own meter, meaning each charger serves five buses. From here on, the example will focus on one charger, serving half of the fleet. A conservative estimate is that each bus charges for 15 minutes and monthly energy usage of 10,000kWh per bus remains the same. Because operation and charging is only during the day, it is assumed that 50% of the electricity usage occurs during the mid-peak period and 50% occurs during the on-peak period.

The rates in Table 1 are for the SDG&E service area with the AL-TOU <500 kW tariff that applies to large utility customers. For this rate schedule there is a meter fee that adds $116 per month to the bill that is not shown in the calculation below. The following table shows the demand costs and usage costs. Note that costs are for each charger, which serves five buses. Doubling the bills (including the meter fee) is representative of the costs for all 10 buses.

Table 2 - Fast Charging 5 Buses at One Charger

Usage Charges	$/kWh		kWh		Total
On-Peak	$0.12	x	25,000	=	$3,000
Mid-Peak	$0.11	x	25,000	=	$2,750
Off-Peak	$0.08	x	0	=	$0
Total Usage Charges (per charger)					$5,750

Demand Charges	$/kW		kW		Total
Maximum Demand	$22.55	x	500	=	$11,275
On-Peak	$19.19	x	500	=	$9,595
Mid-Peak	$0.00	x	500	=	$0
Total Demand Charges (per charger)					$20,870

Monthly Total (Summer, **5** buses)	$26,620
Monthly Total (Summer, **10** buses)	$53,240

Because there is charging on-peak and charging is done for a full 15 minutes, demand costs are considerably higher than in the slow charge example. The total bill for this summer example is $53,240 and equates to about $1.33 per mile.

As long as the number of buses per charger is the same, each bill will be identical (assuming each charger is within the territory of the same utility). For example, above, every charger serving five buses will have the same usage and the same charges. Having one charger charging five buses yields a $26,620 bill, which is $1.33/mile ($26,620/20,000miles). Three chargers charging 15 buses yields a total bill of $79,860 (three $26,620 bills) which is still $1.33/mile ($79,860/60,000miles). Effectively, this means that bus expansion is scalable in groups of five buses.

However, decreasing the number of buses per charger will greatly increase cost per mile. Just using one bus on a fast charger will still yield the same demand and demand charge of $20,870. Though energy usage will decrease with one bus, the total bill will be $22,020 for one bus ($5.51/mile). But spreading necessary demand charges across multiple buses without changing peak demand means more miles per dollar and more reasonable costs.

In practice, buses may not charge for a full 15 minutes at a time. Buses at Foothill Transit charge for five minutes at a time[2], which greatly decreases metered maximum demand. If all buses are charged for no more than 5 minutes, demand would be reduced to 167kW (500kW x [5min/15min]). The demand charge would be reduced from $20,870 to $6,970 ($0.32/mile)

It is important to note that these fast charge examples put chargers at different locations. However, when two chargers are at a transit hub, both are on the same meter. This tandem charging will double demand if both chargers are used at the same time. This is particularly important to keep in mind if it changes rate schedule eligibility. For example, schedule EV4 with Southern California Edison is only applicable below 500kW. If there are two chargers on a meter and demand goes above 500kW, then the user cannot use the EV4 rate and will need to use a standard rate schedule.

There are, however, many ways of decreasing demand costs. The fast charge example above assumes buses charge for 15 continuous minutes, which is a worst case scenario. Because peak demand is an additive cost to maximum demand, decreasing charging during peak hours can reduce costs. One strategy is charging for shorter periods during peak hours and slowly discharging the battery until peak hours are over and the battery can be fully charged at a lower cost. Many manufacturers incorporate onboard software to control vehicle charging.

---

[2] National Renewable Energy Laboratory. Foothill Transit Battery Electric Bus Demonstration Results. (http://www.nrel.gov/docs/fy16osti/65274.pdf)