Engineering Feasibility of Roadway Electrification in a High-Occupancy-Vehicle Facility

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The preliminary engineering feasibility for early deployment of a roadway-powered electric vehicle in El Monte Busway (a 3+ high-occupancy-vehicle facility in Los Angeles) is assessed. The evaluation consists of the determinations of the scale of electrification, locations to be electrified, mode of operation, level of energy transfer, and energy consumption. These analyses are accomplished through vehicle simulation. The evaluation results indicate that systems that combine the electrified roadway and static chargers or those that use static chargers exclusively can be deployed in El Monte Busway. A plan for the technology demonstration is developed. Hardware costs for this plan are estimated.

Concern over air quality in California has led the state to enact a law requiring that 2 percent of all vehicles sold by 1998 and 10 percent sold by 2003 be "emission-free" vehicles. Electric vehicles (EVs) are generally considered to be emission free because they do not emit pollutants while running on the road or stopping in traffic, although power plants supplying electric power to them do emit pollutants. Large-scale use of EVs has not materialized because they have limited range between battery recharges; in addition, the existing battery technology requires 6 to 8 hr for a full recharge. One way to increase the range of Evs between overnight battery recharging in the absence of advanced battery technologies is through the use of roadway-powered electric vehicles (RPEVs).

RPEVs are hybrid electric-electric vehicles (*1–3*) that use an inductive coupling power transfer principle, in which energy stored in an on-board battery is supplemented by energy transferred to the vehicle through an inductive coupling system (ICS). The ICS uses a magnetic field to transfer power across an air gap from the roadway inductor (buried underneath the pavement) to the vehicle. This system can be thought of as a large transformer with an air gap. The primary source of this transformer is the roadway inductor, and the secondary source is the pickup inductor. RPEVs can operate both on and off electrified roadways. On the electrified roadway, they draw power directly from the roadway for use in propelling the vehicle. The balance of this roadway power that is not used is stored as a reserve in the on-board battery. Off the electrified roadway, the vehicles rely solely on the on-board battery power. Electrified roadways do not present electric shock hazards and thus can be shared by pedestrians and nonelectric vehicles. The RPEV technology can be applied to both transit buses and private passenger vehicles.

As part of RPEV research at California PATH and the Playa Vista Project in southern California, a prototype bus and a G-van (a full-sized van) were built and tested. The prototype bus is a low-frequency system with high roadway current (400 Hz and 1,200 amp-turns, respectively). The prototype G-van is a high-frequency system with low roadway current (8,500 Hz and 240 amp-turns, respectively). Design engineers now believe that high-frequency systems with low roadway current are more suitable for the highway application. To advance this technology toward full maturity, a case study was initiated to determine the engineering feasibility of early RPEV deployment in El Monte Busway, an existing 3+ high-occupancy-vehicle (HOV) facility in Los Angeles.

STUDY OBJECTIVE

The objective of this paper is to evaluate the preliminary engineering feasibility of early deployment of the RPEV technology in El Monte Busway and to suggest a plan for early technology demonstration in this HOV lane.

DESCRIPTION OF EL MONTE BUSWAY

El Monte Busway is an exclusive-access HOV lane, not an exclusive bus lane as its name may imply. It is located on I-10 (the western end of San Bernardino Freeway). It is about 18.6 km long, with its western end originating in downtown Los Angeles (at Alameda Street). To the est, the HOV lane ends at the El Monte bus terminal. This HOV lane has one travel lane in each direction, with the two directions separated from each other by permanent barriers. For about 4 mi at the western end, the HOV lane is separated from the freeway mainline by permanent barriers. For the remaining length, the HOV lane is separated from the freeway mainline by buffers at least 1.2 m wide. Access and egress to El Monte Busway are through exclusive ramps.

Being a 24 hr HOV facility, El Monte Busway opens to private passenger vehicles and buses with at least three occupants. Peak traffic flow in the busway is over 1,200 vehicles per hour per lane. There are over 500 bus trips per day in both directions combined.

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METHODOLOGY

Although roadway electrification can be applied to private passenger vehicles, transit buses are more likely to be early users of this technology, particularly before the critical mass of the electrified roadway is achieved. Therefore, transit buses are selected as the design vehicle in this paper. The engineering feasibility evaluation of RPEV in El Monte Busway involves the determinations of functional requirements for a proposed system, electrification scale and energy transfer level, energy consumption, and preliminary design of the ICS. The analyses of the electrification scale, energy transfer level, and energy consumption are accomplished through vehicle simulation, using an electric-vehicle simulation model called EVSIM (*4*). The vehicle simulation requires the following data input:

1. The following information on bus lines currently operating on El Monte Busway was compiled: route length and layout, scheduled bus travel time and stops, dwell time at bus stops, layover time, travel speed, and roadway grades. Nine bus lines were analyzed (Table 1). The posted bus numbers were recoded in ascending order of route length (using numbers 1 through 9), as shown in the last column of Table 1.
2. Characteristics of the hypothetical El Monte bus are as follows: gross vehicle weight, 13 930 kg; maximum acceleration, 3 m/sec^2; drag coefficient, 0.60; rated motor base speed, 1,600 rpm; gear ratio, 28 rpm/km/hr; battery voltage, 500; and battery amp-hour rating, 400.
3. The roadway excitation of the El Monte system is assumed to have a frequency of 8,500 Hz.

FUNCTIONAL REQUIREMENTS FOR RPEV SYSTEM

An RPEV system for early deployment in El Monte Busway should have the following functional requirements:

1. It should provide adequate energy for transit buses to operate continuously for at least 15 hr/day between overnight battery rechargings.
2. The on-board battery should not be discharged below 80 percent at any time during normal daily operation. The purpose of this depth-of-discharge (DOD) limit is to maximize the battery life as well as to provide reserve capacity for the buses to operate on the battery power alone for a couple of hours in case of power failure.
3. The ICS output current required should be limited to 300 amp (at 500 V). This limit, based on knowledge gained from RPEV research at California Partners for Advanced Transit and Highways (PATH) and Playa Vista, aims to minimize roadway loss, system costs, and environment concerns over the electromagnetic fields (EMFs).

ANALYSIS RESULTS

Results are presented for the roadway electrification scale; roadway locations to be electrified, mode of operation (dynamic or static charging), ICS output current, and energy consumption. The dynamic mode of operation refers to power transfer from the electrified roadway to the vehicle that occurs while the vehicle is moving. The static mode of operation uses relatively short sections of static chargers (3 to 5 m long), and the energy transfer occurs only while the vehicle is stationary atop these static chargers. Static chargers can be installed at bus stops and layover points to provide quick battery recharges during routine stops and layovers. Static chargers can be an important energy source for roadway-powered electric buses, because 1 min of static charging could provide energy equivalent to that drawn from 1 mi of the powered roadway. Short discrete sections of static chargers are much less expensive than roadway electrification.

Scale of Electrification for El Monte Busway

To determine the amount of roadway electrification required, three electrification scenarios (A through C) are evaluated, in which the travel lanes of El Monte Busway are electrified and static chargers are installed at selected locations. These three scenarios examine operation of existing bus lines that currently use El Monte Busway with no changes to routes or

TABLE 1 Characteristics of Existing Bus Lines Using El Monte Busway

Actual Route Number	Destination	Round Trip Length (kms)	Round Trip Time (including layovers) (minutes)	Total Layovers (minutes)	Average Velocity (including layovers) (km/hr)	Average Velocity (excluding layovers) (km/hr)	Recoded Bus Number*
480	Pomona Express	109	192	39	34.1	43.0	5
491	Sierra Madre	70	123	14	33.9	38.2	1
481	West Covina	83	157	25	31.8	37.8	2
497	Montclair	120	212	34	34.1	40.5	6
486	Puente Hills	86	180	23	28.6	32.6	3
482	Pomona	141	297	54	28.5	34.9	8
484	Ontario Airp.	139	318	60	26.2	32.3	7
488	Glendora	108	259	39	25.1	29.6	4
490	Fullerton	153	296	40	31.0	35.8	9

* Recoded bus number is in an ascending order of the route length

schedules; new roadway-powered electric buses would simply replace the existing diesel buses. This is viewed as the preferred implementation. Two more scenarios (D and E) in which static chargers are to be used exclusively, without electrifying the travel lanes of El Monte Busway, are also evaluated. The first three scenarios are evaluated first and described below.

Scenario A: Electrify El Monte Busway and Install Static Chargers at Bus Stops and Layover Points

Scenario A proposes an extensive electrification scale. It involves electrifying the entire length of the travel lanes in both directions of El Monte Busway. In addition, static chargers will also be installed at bus layover points of each bus line (i.e., the origin and destination of the bus line), as well as at downtown bus stops used by these bus lines.

Scenario B: Electrify El Monte Busway and Install Static Chargers at Bus Layover Points

Scenario B proposes a less extensive electrification than Scenario A. It involves electrifying the entire length of the travel lanes in both directions of El Monte Busway as well as installing static chargers at the layover points of each bus line. However, static chargers will not be installed at downtown bus stops used by El Monte buses.

Scenario C: Electrify El Monte Busway Without Using Static Chargers

The electrification scale proposed for Scenario C is less extensive than those for Scenarios A and B. Scenario C involves electrifying the travel lanes in both directions of El Monte Busway without installing static chargers at the bus layover points or downtown bus stops.

To be considered viable for implementation, each scenario must be capable of providing adequate energy for all bus lines to operate continuously for at least 15 hr/day, without the battery DOD exceeding 80 percent at any time during normal daily operation. Further, the ICS output current required should not exceed 300 amp. The simulation results from the EVSIM model indicate that Scenario A could meet this daily range requirement for all bus lines currently operating on El Monte Busway. On the other hand, Scenarios B and C are found to fall short of meeting this requirement because both scenarios require ICS output current greater than 300 amp to meet the 15-hr daily range requirement for a number of longer bus lines. Therefore, Scenarios B and C are excluded from further discussion in this paper. Detailed results for Scenario A are presented below.

Battery DOD Profile for One Round-Trip Under Scenario A

Bus Line 3 is used to illustrate the simulation results on the battery DOD profile obtained from the EVSIM model. The battery DOD profile for Line 3 for one round-trip under Scenario A is shown in Figure 1. The vertical axis represents battery discharge, and thus a higher positive value indicates that the battery actually has less charge available. Two battery discharge profiles are shown—one for the ICS output current of 250 amp and the other for 300 amp. The figure indicates that, other things being equal, the magnitude of the battery DOD will decrease as the ICS output current increases.

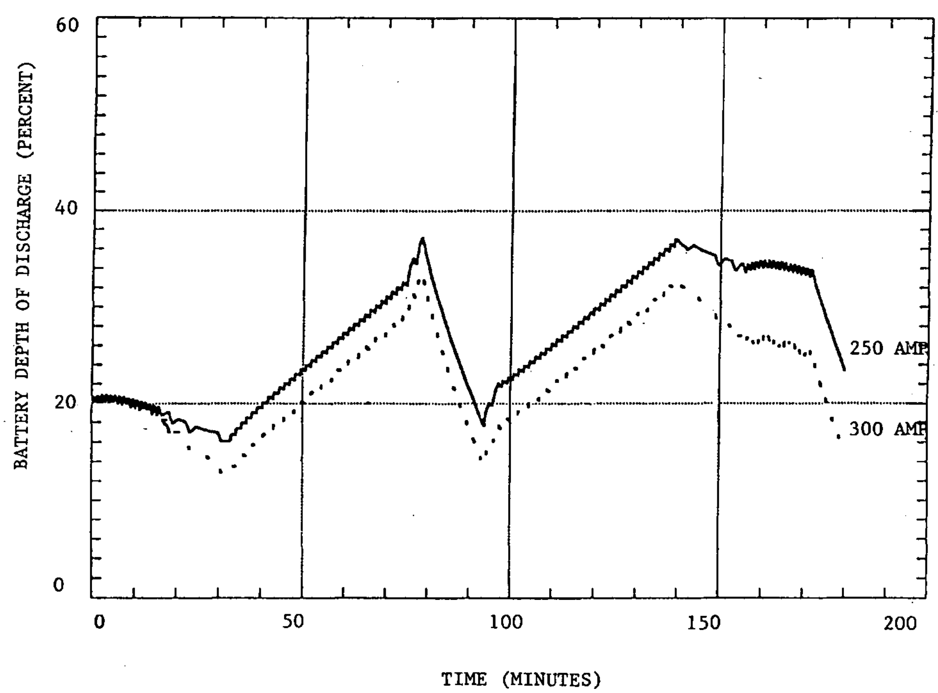

FIGURE 1 Battery discharge profile for Bus Line 3.

Figure 1 shows a battery DOD profile for any one round-trip for Bus Line 3. This particular round-trip starts in the downtown area with 20 percent DOD. The bus traverses downtown streets and then goes onto El Monte Busway (Minute 0 to Minute 30). Figure 1 indicates that there is slight net charging of the battery both in the downtown area (because of static chargers) and on El Monte Busway (because of the electrified lane), indicating that more energy is transferred to the bus than is used. Between Minute 31 and Minute 77, the bus traverses the unpowered suburban portion of the route. At the end of the line, there is net discharge of the battery, which reaches a peak DOD of 37 percent (or 17 percent higher than the DOD at the start of this particular round-trip). Figure 1 also shows that there are very short intervals of battery charging (decreases in the battery DOD) every block because of regenerative braking. This is evident by the ripples, which are farther apart in the suburb than in the downtown, indicating longer distances between stops in the former. The bus then stays idle at the layover point from Minute 78 to Minute 93 while the battery receives a recharge from the static charger. Next, the bus starts the trip back toward the downtown by traversing the suburban portion of the route between Minute 94 and Minute 140. During this time, there is battery discharge until the bus reaches El Monte Busway. From then on, there is net battery charging on El Monte Busway and downtown streets. Finally, at the downtown layover point (Minutes 172 to 180), there is again net battery charging from the static charger at the layover point.

Battery DOD profiles for the other eight bus lines all exhibit patterns of battery charging and discharging for the downtown area, El Monte Busway, the unpowered suburban portion of the route, and layover points similar to that for Bus Line 3, with the actual DOD values varying from bus line to bus line.

Power Transfer Level Required for Scenario A

Consider Figure 1 with the output current of 250 amp. The net change in battery DOD for Bus Line 3 in one round-trip (defined as the difference in DOD levels between the end and the start of that round-trip) is about 3 percent. Therefore, at the start of the next round-trip, the DOD level will be 3 percent lower than that at the start of this trip. Because it takes 3 hr for Line 3 to complete one round-trip, the hourly net battery DOD rate for Line 3 (defined as the difference in DOD levels between the end and the start of one round-trip, divided by the round-trip time) is 1 percent per hour.

The hourly net battery DOD rate for Bus Line 3 at 250 amp, together with the peak DOD reached during a round-trip, suggests that the battery could be discharged to the critical 80 percent level sometime during the 22nd round-trip, if the bus starts the day with a fully charged battery. At the start of the 22nd trip, the battery DOD would be approximately 63 percent. Adding the peak instantaneous DOD of 17 percent (which occurs at approximately Minute 77 of a round-trip) yields the 80 percent DOD value. This implies that an output current of 250 amp could allow Line 3 to operate for at least 21 round-trips (or a total of 63 hr) before the battery discharge would drop to 80 percent. Therefore, the ICS output current of 250 amp is more than adequate for the 15-hr daily range requirement of Line 3.

Strictly speaking, battery performance is not totally independent of the prevailing DOD value. As the battery DOD increases (i.e., the battery has less charge available), the battery can usually receive charge slightly more quickly. As a result, higher initial battery DOD values could yield slightly lower hourly net DOD rates. Therefore, the above projections of the daily range and ICS output current for Bus Line 3 (which assume that the average DOD at the start of all round-trips is about 20 percent) are accurate to the first order of approximation.

Examinations of the battery DOD characteristics for all nine bus lines indicate the following:

1. The ICS output current of 250 amp is adequate to ensure the 15-hr daily operation for Bus Lines 1, 2, 3, and 5.
2. Bus Lines 4, 6, 7, and 8 require the ICS output current of 300 amp to ensure the 15-hr daily operation.
3. Line 9, which is the longest bus line (i.e., 153 km for one round-trip, which takes almost 5 hr to complete), requires the ICS output current greater than 300 amp for 15-hr daily operation. However, a number of measures can be applied specifically to Line 9 so that it can operate for at least 15 hr per day with the ICS output current of 300 amp. These measures include (*a*) providing additional layover time at the existing layover points for more recharging time from static chargers and (*b*) identifying additional layover points along the very long suburban portion of the route for installations of additional static chargers.

The above analysis results suggest that Scenario A could be implemented with the ICS output current level of 300 amp.

Energy Consumption Under Scenario A

Net energy flow into the motor controller (i.e., energy consumption) under Scenario A is also determined from the EVSIM model. The results indicate that energy consumption for all bus lines does not differ much from one another and does not appear to be sensitive to the route length. Energy consumption values for all nine bus lines are found to range from 1.41 kW-hr/km (for Line 5) to 1.58 kW-hr/km (for Line 4).

Exclusive Use of Static Chargers on El Monte Busway

Because of the ease of implementation and lower infrastructure costs of static chargers (compared with the dynamic roadway electrification), it is of particular interest to determine whether static chargers can be used exclusively on El Monte Busway and in the downtown area without having to electrify the travel lanes of El Monte Busway. One scenario investigated is called Scenario D (or the downtown/El Monte shuttle bus service). Scenario D provides a shuttle bus service between the downtown area and El Monte Bus Terminal (Figures 2 and 3). The route for the downtown/El Monte shuttle bus essentially consists of two connecting loops: the downtown loop between Venice Boulevard and Union Station (Figure 3) and the El Monte loop between Union Station and El Monte Bus Terminal (Figure 2). The downtown loop is iden-

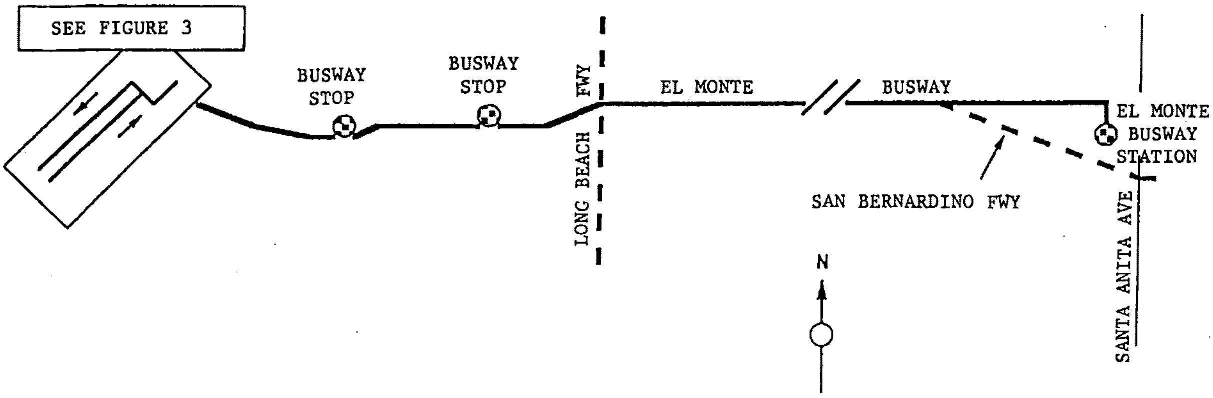

FIGURE 2 El Monte loop for Scenario D.

tical to the route of many Southern California Rapid Transit District buses and is similar to the existing downtown DASH bus service currently operated by Los Angeles Department of Transportation. The downtown/El Monte shuttle bus would start from Venice Boulevard, proceed onto Olive Street, First Street, Spring Street, and Aliso Street. It then lays over at Union Station before continuing onto El Monte Busway toward El Monte Bus Terminal. The shuttle bus, after the layover at El Monte Bus Terminal, would turn back toward Venice Boulevard.

Scenario D involves installing static chargers at downtown bus stops used by this shuttle bus as well as at three designated layover points (El Monte Bus Terminal, Union Station in downtown, and Venice Boulevard at the downtown end of the shuttle). Under Scenario D, the travel lane of El Monte Busway will not be electrified, which is why the infrastructure cost for Scenario D can be significantly reduced. The downtown/El Monte shuttle buses will be roadway-powered electric buses.

The role of static chargers used in Scenario D is to ensure that the shuttle bus can operate continuously for at least 15 hr/day without the battery DOD exceeding 80 percent. These static chargers are not meant to keep the on-board battery fully (or close to fully) charged at all times during the daily operation. Rather, by providing regular battery charging while the bus is in operation (i.e., short-duration charging at the bus stops and longer-duration charging at the layover points), it is possible to prevent the battery from being discharged below 80 percent during daily operation.

Scenario D offers a low-cost option for an early demonstration of RPEV technology. In particular, technology demonstration of the exclusive use of static chargers could precede the eventual and more expensive electrification of the travel lanes of El Monte Busway. In this way, real-world data could be collected to gain further understanding of various design aspects of RPEVs, such as impacts of vehicle loading and air conditioning on energy consumption, energy consumption under freeway and city street operating conditions, energy transfer characteristics, and battery performance and life.

Simulation using the EVSIM model is performed to determine whether Scenario D could provide adequate energy to enable the downtown/El Monte shuttle bus to operate con-

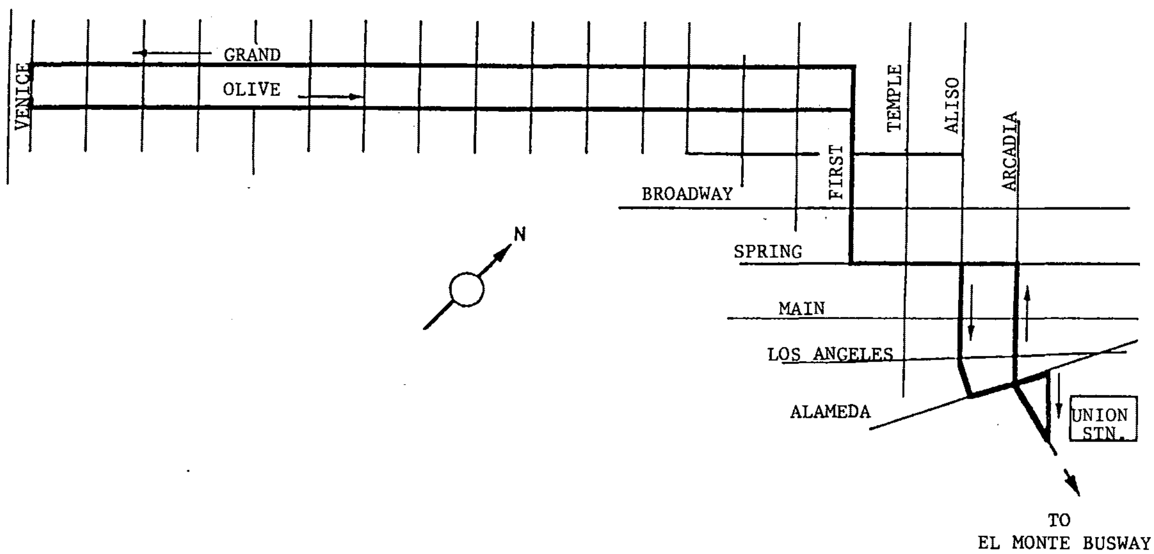

FIGURE 3 Downtown loop for Scenario D.

tinuously for at least 15 hr/day. The simulation results indicate that the total layover time (at the three layover points) in one round-trip affects the capability of Scenario D in supplying the adequate daily range for the shuttle bus. Longer layover time allows more time for battery recharging but increases the round-trip time. Higher round-trip time in turn implies that more buses will be needed to provide a particular service headway.

Figure 4 shows the hourly net battery DOD rate for Scenario D for four values of the round-trip time (75, 80, 85, and 90 min). Figure 4 indicates that the net battery DOD rate decreases with increasing values of the ICS output current up to 300 amp, beyond which no significant decline in this rate is expected. This implies that output currents greater than 300 amp are of no value for Scenario D. Figure 4 indicates that it is feasible to operate the downtown/El Monte shuttle service with the round-trip time of at least 80 min, with the output current of 275 to 300 amp, for 15 hr/day without the battery DOD exceeding 80 percent. For the round-trip time of 80 min, about 15 min would be layover time.

This paper also investigates a special limited case of Scenario D, in which shuttle buses could serve only the downtown loop between Union Station and Venice Boulevard (Figure 3) without serving El Monte Busway and El Monte Bus Terminal. This limited case will be called Scenario E (or the downtown shuttle bus service). Scenario E could have two layover points (at Union Station and Venice Boulevard) and involves only city streets. The simulation of the battery DOD for this downtown shuttle service indicates that it is feasible to use static chargers exclusively at these two layover points and at some bus stops along the downtown loop to provide adequate energy for the downtown shuttle bus to operate continuously for at least 15 hr/day, using the ICS output current of 300 amp. Specifically, the simulation indicates the following:

- Additional static chargers installed at all bus stops along the downtown loop (a total of about 38 stops) would enable the downtown shuttle bus to run indefinitely, if the round-trip time is at least 35 min, without the need for overnight battery recharging. For the round-trip time of 35 min, about 2 min is layover time.
- Additional static chargers installed at about 50 percent of the downtown bus stops (about 19 stops) would enable the downtown shuttle bus to operate for 15 hr/day with the round-trip time of at least 35 min, without the battery DOD exceeding 80 percent. However, the on-board battery has to be recharged overnight at the end of each daily operation.
- Additional static chargers installed at four to five downtown bus stops would enable the downtown shuttle bus to operate for 15 hr/day with the round-trip time of at least 40 min (about 7 min of which is layover time). Also, the battery has to be recharged overnight at the end of each daily operation.

Sharing of Power with Private Vehicles

The simulation results indicate that Scenarios A, D, and E are all viable in terms of providing adequate energy to satisfy the daily range requirement for transit buses. Under Scenario A, roadway-powered electric cars, vans, pickup, and so on, in addition to buses, can also draw power from the electrified travel lanes of El Monte Busway. On the other hand, Scenarios D and E are targeted to serve roadway-powered electric buses, with virtually no practical use for other vehicle types. This is because roadway-powered electric private passenger vehicles would not want to make frequent stops at bus stops or layover points to charge the batteries. From the bus operation's standpoint, it is also undesirable for the buses to share stops and layover points with private passenger vehicles.

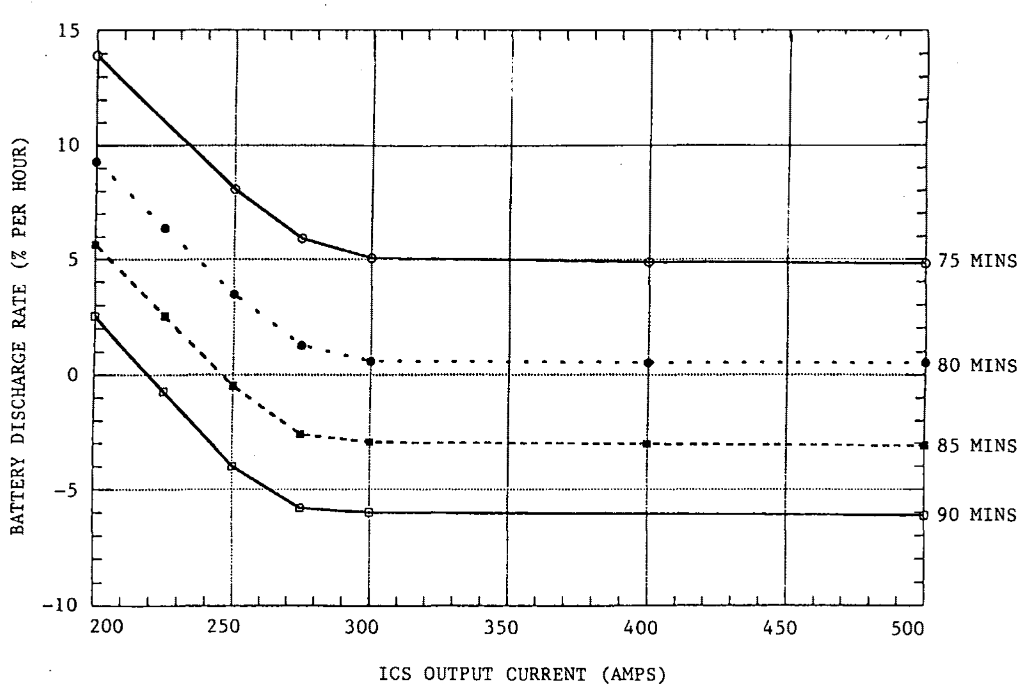

FIGURE 4 Hourly average net battery DOD versus output current (Scenario D).

ICS DESIGN FOR EL MONTE SYSTEM

Figure 5 shows the cross section of an ICS for the El Monte system, which consists of the roadway core and the vehicle pickup core. This ICS would operate at a power frequency of 8,500 Hz. Nominal operating point of this ICS has a roadway excitation of 250 amp-turns. This yields output current of 150 amp for one pickup (assuming a 7.5-cm air gap). Therefore, two pickups in parallel will provide an output current of (2 × 150) or 300 amp, as needed.

Roadway Cores

The roadway core module will be cast as a single W core, with a single multiple-conductor cable in each conduit. The roadway core module is made by embedding the core pieces, along with the conductor conduits, in a concrete matrix. A layer of fiberglass cloth and epoxy or polyester resin is applied over the cores.

Vehicle Pickup

The pickup cores will be the standard "hat section" type, made from hydraulically formed and oven-annealed laminations. For transit buses, split pickups with two 3-m-long sections would be used. Pickups for automobiles could be 1.5 m long. Flat-bar aluminum conductors are used for the conductor packs, which are encapsulated in fiberglass-reinforced epoxy to form a structural beam.

Power Conditioner and Distribution System

The power distribution system carries power from the power conditioners to individual roadway inductor segments. These segments are energized individually and activated only when an RPEV is present. The power distribution system senses the presence of vehicles equipped with the ICS and switches the segment on and off accordingly. Each power conditioner for the El Monte system can power 0.5 mi of travel lanes in both directions.

TECHNOLOGY DEMONSTRATION PLAN

A plan for the technology demonstration of the RPEV consists of two incremental phases, as described below and summarized in Table 2.

Phase 1: Implement Static Chargers Exclusively

The technology demonstration could start with the downtown/El Monte shuttle bus system (Scenario D) or the limited downtown shuttle bus system (Scenario E).

Selection of Scenario D

If Scenario D is selected, the route for the downtown/El Monte shuttle service is as shown in Figures 2 and 3. Static chargers would be required at the three bus layover points shown in the figures as well as at all downtown bus stops that lie along the downtown loop. Altogether, about 41 static chargers would be required. The round-trip distance for the downtown/El Monte shuttle service is about 43.7 km. This shuttle service could operate with total round-trip time of 80 min (of which about 15 min are layover time at the three layover points). To provide 10-min service headway, at least eight roadway-powered electric buses will be required.

Selection of Scenario E

If instead, Scenario E is selected for the demonstration in Phase 1, the route for the downtown shuttle service would involve only downtown streets and two layover points (at Union Station and Venice Boulevard), as shown in Figure 3. The round-trip distance for this shuttle service is about 8.5 km. Static chargers would be installed at the two bus layover

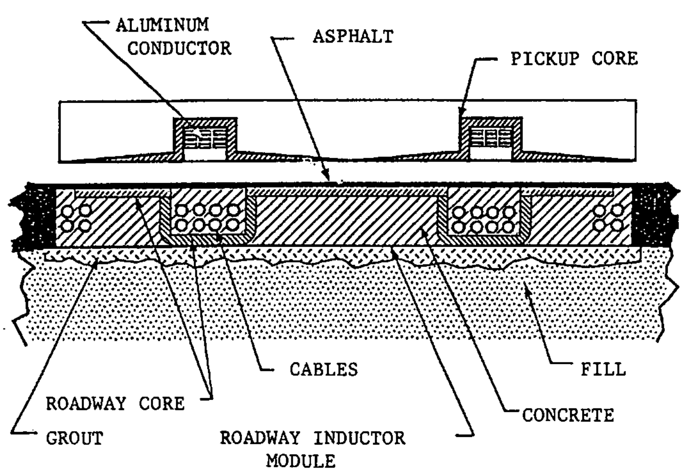

FIGURE 5 Cross section of ICS for El Monte system.

TABLE 2 Technology Demonstration Plan and Hardware Costs

Phase	Bus Headway (mins)	Round-Trip Distance (kms)	# Bus Required	# Static Chargers at Layover	#Static Chargers at Bus Stops	Kms. of Electrified Roadway	Hardware Cost ($ million)
Phase 1:							
o Downtown/El-Monte Shuttle Service	10	43.7	8	3	38	none	6.3
or							
o Downtown Shuttle Service	5	8.5	8	2	5	none	4.3
Phase 2: Electricity El-Monte Busway; operation of 9 bus lines	30*	**	68	12	38	about 36	91.8***

* The bus lines have average service headway of 30 minutes.

** Round-trip distance depends on the bus line.

*** This is an incremental amount over the $6.3 million spent in Phase 1.

points as well as at four to five bus stops along the downtown loop. The downtown shuttle bus could operate with the round-trip time of 40 min (about 7 min of which are layover time). To provide 5-min service headway, at least eight roadway-powered electric buses will be required.

Phase 2: Electrifying Travel Lanes of El Monte Busway

In Phase 2 of the demonstration, Scenario A could be implemented. This would involve electrifying about 36 lane-km of the travel lanes of El Monte Busway, as well as installing static chargers at the layover points of each of the nine bus lines and downtown bus stops. The static chargers previously installed in Phase 1 will become an integral part of the Phase 2 system. This scenario would enable all bus lines operating on El Monte Busway now to maintain their current routes and schedules; roadway-powered electric buses would simply replace existing diesel buses. It is estimated that under Scenario A, at least 68 roadway-powered electric buses would be required to provide service headway of 30 min.

Projected Hardware Costs for Technology Demonstration Plan

The hardware cost for RPEV systems includes the roadway subsystem (roadway inductor, power conditioners, and distribution system), engineering, roadway installation, vehicle, and vehicle equipment (pickup core and inductor, on-board power electronics, battery, on-board controls, and low-power vehicle steering system). There are uncertainties in estimating the hardware cost because the RPEV technology has not yet advanced to a product-development stage. Estimated hardware costs presented in this paper should be considered as approximations.

Because hardware costs for large-scale production are likely to differ from those for initial deployment, projected unit costs shown below are assumed to vary by the quantity used, as follows:

Item	*Cost*
Static chargers	$80,000 per charger for the first four, $60,000 per charger for the remainder
Electrified road	$2.5 million per lane-km for the first four, $1.9 million per lane-km for the remainder
Buses	$600,000 for the first bus, $450,000 per bus for the next 10, and $350,000 per bus for the remainder

Hardware costs for the two phases are shown in Table 2 (last column). Hardware costs for Phase 1 are estimated to be $6.3 million if the downtown/El Monte shuttle service (Scenario D) is selected for the demonstration. If the downtown shuttle service (Scenario E) is selected instead, hardware costs for Phase 1 would be lower ($4.3 million). This is because fewer static chargers are required for Scenario E than for Scenario D.

Estimated hardware costs for Phase 2 represent an incremental amount over the costs for the downtown/El Monte shuttle service. Estimated incremental hardware costs for Phase 2 are $91.8 million. Of this amount, about 76 percent is the cost of electrifying about 22 lane-mi of El Monte Busway, and the remaining 24 percent is the cost of acquiring 60 additional roadway-powered electric buses (eight buses already will have been acquired in Phase 1, which will be available for use in Phase 2). The estimated $91.8 million does not take into account the future savings from not having to replace 68 existing diesel buses when their service lives expire.

Energy Cost for RPEV

The energy cost for internal combustion–engine vehicles includes gasoline and oil, whereas the energy cost for the RPEV is primarily the electricity needed for charging from the roadway and overnight battery recharging. The estimation of energy costs for roadway-powered electric buses, full-sized vans, and cars assumes the following:

1. Average electricity cost is 6 and 10 cents/kW-hr (*5*) for overnight battery charging and roadway charging, respectively.
2. Energy consumption values for buses, vans, and cars are 1.56, 0.31, and 0.13 kW-hr/km, respectively (*5*).
3. Buses draw 80 to 85 percent of energy from the electrified roadway and 15 to 20 percent from overnight recharging. Roadway-powered electric vans and cars draw 25 percent of energy from the electrified roadway and about 75 percent from overnight recharging.

Estimated energy costs for roadway-powered electric buses, full-sized vans, and cars are found to be 14.7, 2.2, and 0.9 cents per vehicle-km of travel, respectively.

IMPACTS OF THE EL MONTE SYSTEM

The proposed plan for early deployment of the RPEV in El Monte Busway is a limited use of the technology. Therefore, environmental and energy impacts resulting from this early deployment are likely to be negligible. Later, when the technology has achieved its critical mass, its environmental and energy impacts could become more substantial. Southern California Association of Governments (SCAG) (*6*) and Bresnock et al. (*7*) reported that the primary long-term benefit of large-scale use of the RPEV would be significant reductions in vehicle emissions and dependence on petroleum. Bresnock et al. (*7*) reported that by electrifying over 1600 km of roadways in the SCAG region (assuming that 15 percent of the total VMT was caused by RPEVs) by 2025, peak utility demand could increase by about 1 percent relative to the baseline peak demand in which RPEVs are not deployed. Bresnock et al. (*7*) reported that the magnetic flux density measured from RPEVs was significantly below the standards for EMF exposure set by the International Radiation Protection Association and the International Non-Ionizing Radiation Committee; a flux density outside the vehicle at 1 m above the electrified roadway was lower than that from electric shavers. Possible long-term health and biological impacts of EMF are subjects of many ongoing research efforts, but there has been no conclusive finding to date.

CONCLUSION

The preliminary engineering feasibility study of early deployment of RPEV indicates that it is feasible to deploy a system in El Monte Busway as the first step toward larger-scale implementation on the highway. To advance the technology from its current state to the proposed technology demonstration, a number of activities need to be accomplished. They include detailed system design and specifications for the scenario selected for the demonstration, development and testing of prototype hardware, construction of operational facility and vehicle fabrication, and system shakedown and testing.

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