

Role of the Electric Vehicle as a Distributed Resource

Saifur Rahman
Fellow

Yonael Teklu
Student Member

Center for Energy and the Global Environment, Alexandria Research Institute
Virginia Polytechnic Institute and State University, Alexandria, VA, 22314, USA

Abstract: The growing concern about environmental degradation, and increasing amounts of greenhouse gas emissions from automobiles have generated significant interests among citizens, auto manufacturers and governments around the world to develop affordable and workable electric vehicles. Both fuel cell and electric battery operated vehicles are being considered for commercial deployment within the next five years. The availability of such technologies will offer new opportunities for distributed energy sources for partially meeting household electricity demand. The unique concept presented in this paper deals with using the electric vehicle (EV) as home-based power plant supplying electricity during hours of high price, and under emergency situations. Such dual-use opportunity for the EV will allow the EV owner to get financial benefits that can be used for servicing the car/battery lease expenses. This paper deals with modeling the available capacity for stationary electricity output (while the vehicle is not on the road), the proper charging sequence, forecasting the load servicing capability of the EV battery or the fuel cell, and the system level load impact when the batteries are charged. The load servicing capability of the dual-purpose EV (DPEV) will determine the type of loads and duration of supply that can be provided by the on-board power plant.

Keywords: Distributed Resources, Electric Vehicle, Hybrid-electric Vehicle.

I. INTRODUCTION

Background on Distributed Resources

A fundamental change is taking place in the way electricity is being generated, transmitted and distributed in the country. The traditional system of vertically integrated utilities has been "restructured," i.e., unbundled into functionally separate entities of generation, transmission and distribution with competition having been introduced in the generation and distribution sectors. Restructuring, however, has had some unintended consequences: the most troublesome being increased incidences of transmission congestion and power outages [1][2]. Customers, faced with price volatility as well as a decline in supply reliability and power quality have shown renewed interest in generating electricity from distributed resources and locations. Distributed resources (DR) are small-scale power generation systems sited at or near the point of consumption ranging from a few kilowatts to 50 MW in capacity. Compared to large, central station plants, DRs operate more efficiently and cleanly whilst being flexible, modular and easily scalable. Current DR technologies include solar photovoltaics, wind turbines, battery storage, fuel cells, micro gas turbines and internal combustion engine driven generators.

Although the technologies listed above are mature and commercially available, the next generation of these and other new DR technologies are being developed. The technologies will be more efficient, economic and environmentally cleaner to operate. Above all, the technologies are expected to be smarter in interconnecting with the distribution grid via intelligent interfaces that will handle tasks such as power conditioning, protection, metering, billing and telemetry, in compliance with interconnection requirements [3][4].

Zero-Emission Vehicles as Distributed Resources

Of the DR technologies available, those based on internal combustion engines, micro gas-turbines, fuel cells and battery storage will be the most extensively implemented on account of their lower cost/kW, minimal footprint requirement and dispatchability. Coincidentally, these technologies are used as prime movers in electric (EV) and hybrid-electric vehicles (HEV). Thus, EVs and HEVs, with their storage batteries and advanced power units, can be utilized as power sources and more specifically, as distributed resources that can readily be dispatched within the interconnected system. The paper proposes a scheme whereby the storage battery and/or advanced power unit onboard an EV or a HEV are put to auxiliary use as power in standalone mode or connected to the grid as a true distributed resource. The basic premise is that, after the day's commute, an EV battery will have sufficient residual charge that can be diverted towards servicing conventional loads during evening peak hours. Charging the EV battery for the following trip cycle can resume later at off-peak hours. In a similar manner, the advanced power units of HEVs (such as fuel cells or micro gas-turbine generators) can be dispatched as distributed resources when the vehicles are not being driven on the road. EVs and HEVs playing such a dual role will be referred to as dual-purpose electric vehicles (DPEV) in this paper.

Operating EVs and HEVs as distributed resources maximizes their utility, and hence, the benefits that can be derived thereof. For owners and operators of DPEVs, it means increased supply reliability and power quality. Moreover, the potential revenues from the sale of electricity or the savings accrued from lower energy bills will contribute to reducing the life-cycle costs of DPEVs. For utilities, the benefits of accommodating DPEVs in their systems include peak power and congestion reduction, ancillary type support as well as the deferment of distribution system upgrades and reliability improvements. DPEVs will also have a positive impact on the environment by adding to the benefit already obtained in reducing tailpipe and power station emissions.

II. Review of Zero Emission Vehicles

Electric Vehicles

Like most alternate energy technologies, EVs owe their rebirth to the 1973 oil embargo and the passing of both the Clean Air Act Amendment (CAAA 1990) and the Energy Policy Act (EPA 1992). As a result, federal mandates were passed to phase in clean and alternate fuel vehicles (CFVs and AFVs) in fleet operations [7][8]. The turning point came in 1990 when the California Air Resources Board (CARB) decreed 2% of new automobiles and light-trucks sold in the state be zero-emission vehicles (ZEV) during 1998-2000 increasing to 5% in 2000 and 2001 [9]¹. CARB's ZEV mandate was passed in an endeavor to limit vehicle emissions, which, in 1990, exceeded 1.4 million tons of nitrogen oxide and hydrocarbons [10]. The mandate was quickly emulated by several northeastern states.

The development of electric vehicles is tied to the development of the two key components, namely, batteries and infrastructure. By far the most encumbering factor in EV development has been batteries. With their low energy content (kWh/kg), short charge/discharge cycle life and high cost, batteries in use today have limited the overall performance (range, acceleration, recharge time, payback, etc.) of EVs vis-à-vis conventional vehicles. Similarly, infrastructure development has become an enormous task that remains to be addressed prior to wide scale penetration of EVs. These include, among others, the development of battery-charging equipment and facilities, communication and control systems as well as maintenance, repair, emergency and recycling facilities. A crucial task will be upgrading the electric utility's infrastructure, i.e., generation and distribution capacities, to ensure adequacy and availability in handling EV battery charging loads.

Despite battery and infrastructure limitations, increasing numbers of EVs have been put on the road since the 1990's. By 1995, for example, about 2,400 electric vehicles were on the road [14]. If automakers comply with ZEV rulings (i.e., 4% of all new car sales in California and several Northeastern and Mid-Atlantic States in the form of ZEV), the EV population is expected to grow to 300,000 by the year 2003.

EVs are being developed in various combinations of battery/power conditioner/controller and drive configurations as well as in sizes ranging from subcompacts to minivans and buses as summarized in the technology review by [17]. Typical on-board battery capacity for small vehicles is 15-25 kWh enabling 130-160 kms per charge under normal driving conditions while the specific consumption ranges from 0.16

to 0.64 kWh/kms depending on the type of vehicle. The batteries in use today are shown in Table 1.

Table 1. Typical Characteristics of EV Batteries on the Market [11][12]

Battery Type	Sp. Energy (Whr/kg)	Sp. Power (W/kg)	Life (Deep Cycle)	Cost (\$/kWh)
Lead-Acid	33	100	300-400	200
NiCd	50	150-180	>800	330
NiMH	50-70	150-180	750-1000	>1,000

Source: CARB Report on the Performance and Availability of Batteries for Electric Vehicles.

The present generation of batteries lack in specific energy and power content hence limiting the overall performance of electric vehicles. Advanced batteries with specific energy of 200 Wh/kg and costing under \$100/kWh are currently being developed. In particular, lead-acid batteries that achieve 50 Wh/kg costing under \$150/kWh and capable of handling fast-charges are being developed.

Battery charging has been standardized as Level 1, 2 and 3 depending on power level and location as listed in [13]. Two types of connector couplings - the conductive and inductive system - are currently being used in charging vehicles. The conductive system is simply a multi-pronged plug and depends on the physical contact of the conductors for power transfer while the inductive plug relies on the magnetic coupling of the plug windings and the coil in the vehicle's inlet port to transfer power.

EV drives are available based on either DC or AC motor/controller systems although the latter are more popular due to their reliability and ruggedness. AC controllers are however more expensive than their DC/DC counterparts. Permanent magnet brushless DC motor/controller systems combine the best of both DC and AC drives, i.e., they are multi-speed, highly efficient, versatile, light-weight and less costly than AC drives. An important feature of both AC and DC motor/controllers is regenerative braking in which the momentum of the vehicle is used to recharge the onboard battery. Regenerative braking can extend the vehicle range by as much as 10%.

Hybrid Electric Vehicles (HEV)

The apparent setbacks in the development of advanced batteries and infrastructure for pure EVs has fueled a parallel effort in HEV research. HEVs comprise of power and storage units optimized to work in either series or parallel configuration depending on the design. Typical power units include small gasoline or diesel engines, gas turbines and fuel cells while storage units include batteries, flywheels and ultra-capacitors respectively. HEVs with hydrogen-fed fuel cell power plants and battery storage, for example, are zero emissions vehicles like pure EVs and can serve as distributed resources. The most promising technology for light-duty HEV applications is the Proton Exchange Membrane Fuel Cell (PEMFC) with its high power density and low operating temperature range. HEVs are self-reliant in that the fuel cell power unit is used to charge the onboard battery storage. This reduces or eliminates the need for external source

¹ The mandate has undergone several amendments since its inception. The current version, called LEV II, requires all auto manufacturers with annual sales of more than 3000 new cars to offer 4% as ZEV by the year 2003. The balance 6% will be supplied in the form of low emission vehicles (LEV) and ultra-low emission vehicles (ULEV).

charging such as required by EVs. Like EVs, however, HEVs have infrastructure requirements mostly connected with the production, packaging and distribution of the fuel of choice, i.e., hydrogen.

III. Sample Case Study

The study proposes a DPEV scheme whereby the storage battery and fuel cell power unit onboard an EV or a HEV are put to auxiliary use as power sources. A similar proposal was forwarded in [5] and analyzed in detail in [6] targeting specific sectors that could benefit from DPEVs. To demonstrate the scheme here, a typical suburban commuter is considered. The following assumptions are presented in formulating the sample case study.

Participants: The number of participants is assumed to be some 750 households, 500 EVs and 100 HEVs, evenly distributed in a town and representing no more than 10% penetration level in order to limit possible adverse impacts on the utility as discussed in [18] and [19]. The participants operating EVs have been classified into three groups depending on where the vehicles are charged: 70%, will charge at their homes only while some 20% of the EV operators will have access to charging facilities both at home and near the workplace. The balance, 10%, will depend on the services near the workplace. In contrast, all HEVs owners will charge vehicle battery at their homes during off-peak hours.

DPEV Usage: The vehicles will be used for commuting to and from work usually during the morning hours from 7-9 a.m. and the evening hours from 5-7 p.m. respectively. The daily commute is assumed to be an average of 80 kms as in [15] and [16]. To satisfy the range requirement, medium-sized sedan vehicles were selected with specifications shown in Table 2 and 3.

Table 2. Specification for the Electric Vehicle

Battery Pack	Lead-acid, 25kWh @C-1 rate
Range	130-160 kms
Efficiency	0.16 kWh/kms approx.
Max. (DOD)	85% Depth of Discharge
Charge Time (85% DOD to Full)	6-7 hours (normal charge) 30 minutes - 1 hour (fast charge)

Table 3. Specification for the Hybrid Electric Vehicle

Fuel Cell Unit	PEMFC, 10 kW, 50% efficiency
Battery Pack	Pb-acid, 12 kWh, 0.16 kWh/kms efficiency
Fuel Capacity	Hydrogen, 30m ³ @ 3600 PSI
Fuel	Density 10.9 kg/m ³ , Energy 3.06kWh/m ³
Range	130-160 kms
Configuration	Series drive

EV Charge/Discharge Profile: Charging at home will commence after the evening peak hours and last for 5-7 hours so that EVs start the day with a fully charged battery. Conversely, opportunistic charging will occur during the day at charging stations or outlets on curbsides and in parking

lots. Based on SIMPLEV simulations, a trip 80 kms (consisting of several SFUDS cycles) is expected to discharge a 25 kWh battery pack to a DOD of about 52%². Hence, each commute to and from the workplace will consume about 26%. After the evening commute, the EVs are to be connected to the line in DR mode and deliver power until the maximum allowable DOD of 85% is reached. Charging is to coincide with the evening peak hours of the residential sector.

HEV Charge/Discharge Profile: HEV charging will be performed on two levels: (i) the fuel cell power unit will maintain battery charge between 40% and 100% SOC when the vehicle is being driven, (ii) the home-charging unit will top up the battery pack during off-peak hours so that vehicles start the next day's commute on a full charge. In DR mode, the fuel cell power unit and the battery pack will deliver power to the distribution grid during the evening peak-hours. The fuel cell unit will provide 12 kWh only to conserve on hydrogen while the battery pack will be discharged to its maximum allowable DOD of 85%.

Battery and Power Management: Power management, i.e., vehicle battery charging, DR mode operation and power conditioning, is to be performed by a smart device based on the best available technology. It will be capable of remote communication with vehicle operator as well as with the Local Distribution Company to schedule DR operation as well as perform the necessary charging and discharging tasks according to the peak and off-peak schedule. The components of the power management devices are rated to conform to the ratings of domestic wiring installations at 6.6 kW for the battery charger and 5.0 kW for the inverter.

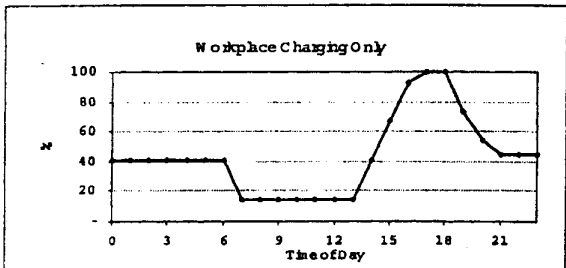
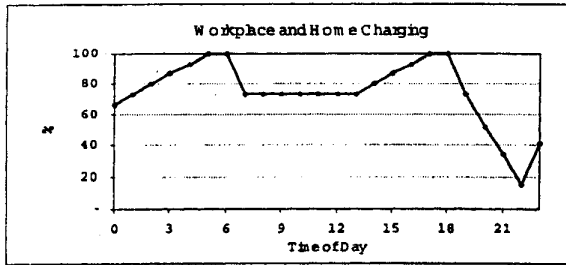
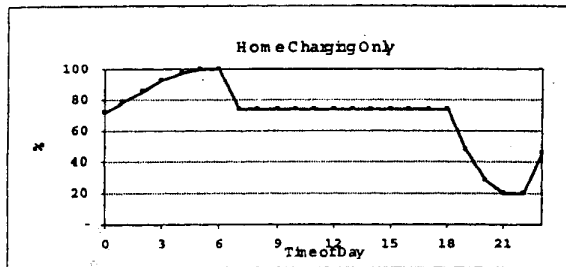
Based on the above assumptions, the charge/discharge profiles of EVs are shown in Table 4.

Table 4. Charge/Discharge Profile of an EV Commuter (% DOD)

	(Vehicles charged at)		
	Home only	Opportunity/Home	Opportunity only
Begin Morning Commute	0	0	59
End Morning Commute	26	26	85
Daytime	Charging at Workplace		
Begin Evening Commute	26	0	0
End Evening Commute	52	26	26
Capacity Available for DR Operation	33% (8.3 kWh)	59% (14.8 kWh)	33% (8.3 kWh)
Night-time	Charging at Home		

Figures 1a, 1b and 1c show the typical battery state-of-charge (SOC) for the three types of participants in the EV lineup.

² SFUDS is the Simplified Federal Urban Driving Schedule used in pacing EVs under test and emulates the stop and go as well as the acceleration and deceleration in a typical urban drive. SIMPLEV is a simulation program developed by the Idaho National Engineering Lab (INEL).



Figures 1a, 1b, 1c. Battery SOC of EVs for the various charging regimes.

Table 5 shows the typical charge/discharge profile of an HEV throughout the day. An energy content of 120MJ/kg (11 MJ/m³) was assumed for the hydrogen fuel.

Table 5. Charge/Discharge Profile of an HEV Commuter (% DOD)

	Battery DOD (%)	Fuel Cell (kWh)	Fuel Consumed
Begin Morning Commute	0	-	-
End Morning Commute	52	-	-
Daytime	FC Charging Battery to 100% SOC	4.4 kWh	2.90 m ³
Begin Evening Commute	0	-	-
End Morning Commute	52	-	-
Capacity Available for DR Operation	33 (4.0 kWh)	12 kWh	7.84 m ³
Night-time (Charging at Home)	Top up 10.2 kWh	-	-

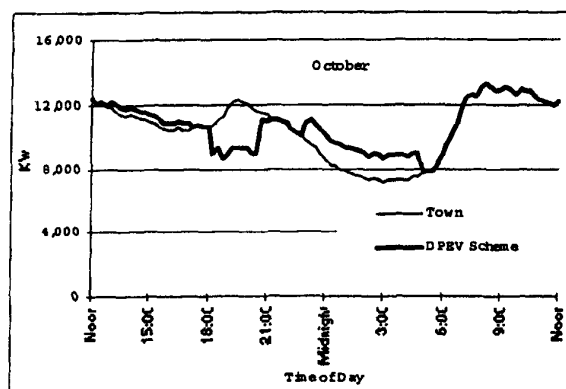
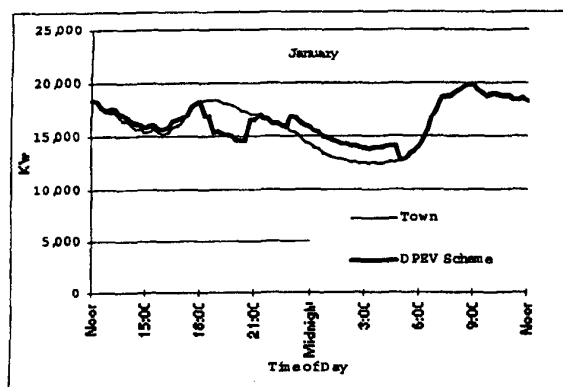
The utility level impact of deploying 600 DPEV in a town is summarized in Table 6.

Table 6. Utility Level Impact of DPEV Use (Based on 10% penetration)

	EV			HEV
	Home only	Opportunity and Home	Opportunity only	Home only
No. of Participants (Total 600)	350	100	50	100
Peak Charging Load - at homes (Kilowatts)	2,310	660	-	660
- at workplaces (Kilowatts)	-	660	330	-
EV Charging Energy - at homes (Kilowatt-hours)	7,438	2,125	-	1,020
- at workplaces (Kilowatt-hours)	-	650	1,063	-
Energy from DPEVs in DR Mode (Kilowatt-hours)	2,905	1,480	415	1,600
Estimated peak hours coverage (Hours)	1.7	3.0	1.7	2.0
Net Charging (Kilowatt-hours)	4,533	1,295	648	-580

Value Assessment: Utilizing EVs and HEVs as distributed resources during peak hours can increase the viability and cost-effectiveness of DPEVs. The benefits of the proposed scheme are twofold: (i). DPEV owners will save on their electricity bills for using less during peak hours and for shifting their charging requirements to off-peak hours by taking advantage of the variety of special rates provided by utilities for such occasions, (ii). DPEV use reduces the need for costly capacity that utilities have to dispatch during peak hours while reducing the stress on distribution equipment from operating near their rated levels. Moreover, it delays the need for expensive upgrading of generation and distribution systems. The proposed scheme is essentially a viable DSM option that can be implemented concurrently with other utility demand management measures. For the utility, the proposed scheme provides reduction in demand via the combined measures of peak clipping and load shifting. Peak clipping is possible since the battery onboard a DPEV is an energy storage that could be tapped during peak demand hours. Load-shifting is inevitable since charging DPEVs can double the kW load of homes unless coordinated with the use of existing high load appliances such as the washing machine, clothes-dryer, water-heater and heat-pump.

Value to the Utility: To demonstrate the impacts on the utility, the data in Tables 5 and 6 were superimposed on the actual load curves of a town as shown in Figure 2a and 2b. The town's load curve has two peaks, the daytime peak 8:00-11:00 a.m. and the evening peak from 6:00-9:00 p.m. The evening peak is attributed mostly to the residential sector. From Figures 2a and 2b, it can be seen that a peak clipping of about 11% can be attained in the town with the DPEV scheme.



Figures 2a and 2b. Load Profile of Town with DPEV Scheme.

Value to the Customer: DPEV owners benefit from a variety of regulatory and utility incentives. These include, among others, federal and state tax breaks, credits towards installing home charging facilities as well as parking and HOV privileges. Incentives from the utility are mainly in the form of special time-of-use (TOU) rates to EV owners that offer cheaper rates for vehicle charging during off-peak hours. Another utility incentive is energy buy-back from customers with DR capability. Most utilities have provisions in place for "net-metering" to accommodate such customers. DPEV owners can therefore reduce their energy bills by paying for the net amount (kWhrs consumed - kWhrs generated).

To demonstrate, the monthly energy expenditures of the three types of EV and HEV operators were compared under the various rate schedules shown in Table 7. The rate schedules are currently provided by a utility in California. A typical all-electric household was used in the example. Electricity consumption was assumed to be 50 kWhrs per day based on data in [20]. The consumption pattern was assumed to be 25% during peak-hours and 75% during off-peak hours. The DPEVs are operated according to the charge/discharge profiles shown in Tables 4 and 5. Net metering was assumed available at prevailing rates. The cost/km for operating the DPEV was estimated by comparing the net vehicle generation to the vehicle miles traveled during the month.

Table 7. Rate Options Available for DPEV Household (cents/kWhr)

Rate Type	Peak	Off-peak I	Off-peak II
Standard	7.82	7.82	7.82
TOU for EV charging only	8.43 [12pm-8pm]	6.12 [8pm-12am] [5am-12pm]	5.84 [12am-5am]
TOU for EV charging + Domestic	8.39 [12pm-6pm]	6.14 [6pm-12am] [5am-12pm]	5.84 [12am-5am]

Based on the assumptions listed above and the rate schedules in Table 7, the estimated monthly expenditures were calculated for both EV and HEV owners as shown in Table 8.

Table 8. Estimated Monthly Payments for Electricity by DPEV Households.

	EV			HEV
	Home only	Opportunity and Home	Opportunity only	Home only
Monthly Consumption (kWhr)	(kWhr)	(kWhr)	(kWhr)	(kWhr)
Monthly Consumption				
- DPEV charging	659	860	659	316
- Domestic use	1550	1550	1550	1550
- DPEV generation	-257	-459	-257	-192
Standard Rate	\$152.61	\$152.61	\$152.61	\$130.89
- DPEV charging	51.52	67.28	51.52	24.71
- Domestic use	121.21	121.21	121.21	121.21
- DPEV generation	-20.12	-35.88	-20.12	-15.03
- Service charge	-	-	-	-
TOU for EV Charging Only	\$143.50	\$144.73	\$156.63	\$128.30
- DPEV charging	39.01	56.00	55.54	18.72
- Domestic use	121.21	121.21	121.21	121.21
- DPEV generation	-20.12	-35.88	-20.12	-15.03
- Service charge	3.40	3.40	-	3.40
TOU for Both EV Charging and Domestic Use	\$129.38	\$133.92	\$142.20	\$113.03
- DPEV charging	39.05	55.96	55.27	18.74
- Domestic use	102.73	102.73	102.73	102.73
- DPEV generation	-15.80	-28.17	-15.80	-11.80
- Service charge	3.40	3.40	-	3.40
Cost/mile DPEV charging	1.22¢	1.29¢	2.06¢	-

The benefits of using DPEVs derive from their role as power generators and the rate incentives that are made available to the operators. From Table 8, it is seen that the TOU rates fare better than the standard rate in most cases. For example, cash benefits due to DPEVs range from \$392 to \$561 annually for operators charging at home only. Similarly, the benefits for HEV owners range from \$252 to \$435. Under the prevailing assumptions, the cost/km for charging will range from 0.8-1.3 cents. In contrast, the cost of energy for a conventional gasoline powered vehicle can be as high as 2.4 cents/km assuming vehicle consumption rate of 14.8 kms/liter and fuel price of \$0.36/liter.

Environmental Benefit: Operating zero emissions vehicles precludes the release of carbon dioxide, carbon monoxide, nitrogen oxides and sulfur oxides as well as a host of hydrocarbons and volatile organic compounds that would otherwise be emitted by conventional vehicles. The environmental impact from increased smoke stack emissions due to the additional EV/HEV charging load is considerably less than the tailpipe emissions as it is easier to mitigate emissions from a limited number of power stations than from 600 vehicles.

IV. CONCLUSIONS

Distributed resources (DRs) are fast becoming an important aspect of the deregulated electric system. Various new and existing technologies are being developed and adapted to serve as DR type power systems. These include internal combustion engines, gas turbines and micro-turbines, fuel cells and storage batteries. These technologies are also being developed and packaged for the next generation of zero-emission vehicles, i.e., electric and hybrid-electric vehicles. Hence, EVs and HEVs can serve as DR units under the appropriate conditions. A ballpark analysis has been presented in this paper to demonstrate the viability of using the storage battery and power unit onboard EVs and HEVs as a possible power sources in the residential setting. The proposed scheme benefits both the customer and the utility. As a DSM option, it will also have a positive impact on the environment in helping reduce emission both from power stations and the use of conventional vehicles. Although the benefits may increase with the level of penetration, at some upper limit, upgrading and refurbishing of local distribution capacity will be unavoidable. In the meantime, the use of advanced batteries, power units as well as more efficient drive and power management systems will increase the fraction of battery energy available to the dwelling, enhancing the viability of the system without sacrificing driving performance.

V. REFERENCES

- [1] L.S. Hyman, "Transmission Congestion, Pricing, and Incentives," IEEE Power Engineering Review, vol. 19, no. 8, August 1999, pp.4-10.
- [2] C.A. Falcone, Transmission in Transition: Bringing Power to Market," IEEE Power Engineering Review, vol. 19, no. 8, August 1999, p. 11.
- [3] J.L. Koepfinger, "Visions of the Electric System of the Future," Proceedings of the 61st American Power Conference on Innovation for Economy and Reliability, Chicago 1999, vol. 61-II, pp. 768-773.
- [4] R. DeBlasio, " Status of IEEE SCC21: Panel Session on Customer Interconnection Requirements for Distributed Generation," 1999 IEEE Power Engineering Society Summer Meeting, Edmonton, Canada.
- [5] W.R. Lachs, D. Sutanto, and D.N. Logothetis, "Power System Control in the Next Century," IEEE Transaction on Power Systems, vol. 11, no. 1, February 1996, pp. 11-17.
- [6] S. Letendre and W. Kempton, "Electric Vehicles as a New Power Source for Electric Vehicles," Transportation Research-D, 1997, Vol. 2, No. 3 pp. 157-175
- [7] J.J. Winebrake, "Federal Law and Vehicle Fleets: Understanding and Integrating Federal Requirements," DOE, January 1994
- [8] DOE, "EPA Initiatives for Alternate Fuel Vehicle, An Integrated Approach for Implementing the Energy Policy Act," March 1995
- [9] T. Cackette, "California's Zero Emission Vehicle Requirements and Implications for Hybrid Electric Vehicles," NIST Special Publications #860, Proceedings of the Advanced Components for Electric and Hybrid Electric Vehicles Workshop, October 27-28, 1993, Gaithersburg, Md., March 1994, pp. 3-11.
- [10] California Air Resources Board and the California Air Pollution Control Officers Association, "Stakeholder Visions for the Future of California Air Quality Management," March 1999.
- [11] F.R. Kalhammer, A. Kozawa, C.B. Moyer, B.B. Owens, "Performance and Availability of Batteries for Electric Vehicles: A Report of the Battery Technical Advisory Panel," California Air Resources Board December 1995.
- [12] T. Moore, The Road Ahead for EV Batteries, "The Road Ahead for EV Batteries," EPRI Journal, March/April 1996.
- [13] C.B. Toepfer, "Special Report: Charge! EVs Power Up for the Long Haul," IEEE Spectrum, vol. 35, no. 11, November 1998.
- [14] EVAA, "EV Population Study," Electric Vehicle Association of America.
- [15] C.W. Gellings, "The Value of a Typical Electric Vehicle," Keynote Address, EPRI TR-106554, Proceedings of the 1995 North American EV and Infrastructure Conference, May 1996.
- [16] Energy Information Administration (EIA), Office of Energy markets and End Use, "1999-1994 Residential Transportation Energy Consumption Survey."
- [17] C.C. Chan, "An Overview of Electric Vehicle Technology," Proceedings of the IEEE, vol. 81, no. 9, Sept. 1993, pp. 1202-1213.
- [18] S. Rahman, G. B. Shrestha, "An Investigation into the Impact of Electric Vehicle Load on the Electric Utility Distribution System," IEEE Transactions on Power Delivery, vol. 8, no. 2, April 1993.
- [19] L. Philipson, "EVs and Power Delivery: Revolution in the Making?," Electrical World, vol. 207, March 1993.
- [20] Department of Energy, "Household Energy Consumption and Expenditures for 1993," DOE, Oct. 1995, DOE/EIA-0321 (93), pp. 22.

Biographies

Saifur Rahman (S-75, M-78, SM-87, F-98) is the Director of Alexandria Research Institute at Virginia Tech where he is a professor of electrical engineering. He also directs the Center for Energy and the Global Environment at the university. Dr. Rahman is currently serving on the Power Engineering Society Governing Board as the Vice President for Education/Industry Relations. He serves on several PES committees and subcommittees including the Education Committee, Energy Development Subcommittee and Customer Products and Services Subcommittee. He is also a member-at-large of the IEEE-USA Energy Policy Committee. He has published over 200 papers on conventional and renewable energy systems, load forecasting, uncertainty evaluation and system planning.

Yonael Teklu (S-96) received B.Sc. and M.Sc. degrees in Electrical Engineering from Addis Ababa University, Ethiopia, and Virginia Tech, USA, in 1981 and 1995 respectively. He is currently working toward a Ph.D. degree at Virginia Tech. His research activities involve energy systems planning, renewable and distributed generation systems.