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One Million Plug-in Electric Vehicles on the Road by 2015

Ahmed Yousuf Saber, *Member, IEEE* and Ganesh Kumar Venayagamoorthy, *Senior Member, IEEE*

Abstract— **It is mentioned that one million plug-in hybrid and electric vehicles will be on the road by 2015 in United States to reduce emission. If one million electric vehicles (EVs) are connected to the existing electric grid randomly, peak load will be very high. Electrified transportation based on a traditional thermal power system will be costly economically and environmentally though it has a great value for electric power and transportation sectors. EVs cannot alone solve the emission problem completely since they need electric power, which is one of the main sources of emission. Therefore, significant emission reduction greatly depends on the maximum utilization of renewable energy. Two models are investigated to show the effect of one million EVs on electric power and transportation sectors. Linear and non-linear systems are used in modeling the emissions generated from the transportation and electric energy sectors respectively.**

Index Terms— **Emission, electric vehicles, load leveling, optimization, renewable energy, smart grid, transportation sector.**

I. INTRODUCTION

THE alarming rate, at which global energy reserves are depleting, is a major worldwide concern at economic, environmental, industrial and community levels [1]. With increasing concern over global climate change, policy makers are promoting renewable energy sources (RESs) for emissions reduction targets. A partial solution to this crisis is (a) the use of decentralized renewable energy, and (b) the widespread use of plug-in hybrid electric vehicles (PHEVs) with vehicle-to-grid (V2G) capability - called “gridable vehicles”. A gridable vehicle is a modified version of a plug-in hybrid electric vehicle or an electric vehicle (EV) for next generation to spark a revolution in the energy and transportation industries. For economical importance, environmental impact and social motivation, new generation vehicles (gridable vehicles) have to have capability of both charging from the grid and discharging to the grid intelligently that utilize RESs properly.

The power and energy industry is one of the most important sectors in the world since nearly every aspect of industrial productivity and daily life depends on electricity. The power and energy industry represents a major portion of global emission, which is responsible for 40% of the global CO_2 production followed by the transportation sector (24%) [2]. The estimated costs of an unabated climate change are as much as 20% of the global domestic product (GDP). However, by taking the appropriate measurements these costs could be limited to around 1% of GDP [3]. Climate change caused by greenhouse gas (GHG) emissions is now widely accepted as a real condition that has potentially serious consequences for human society and industries need to factor this into their strategic plans [4]. So an environment friendly modern planning is essential.

The use of renewable energy may become attractive, especially if, customers would have to pay not only for the cost of generation but also for cost of environmental cleanup and health effects [5]. Secured power systems must have enough generation to meet demand at each moment of the day. In addition, they must also have enough reserve to deal with unexpected contingencies. Stimulated by recent technological developments and increasing concern over the sustainability and environmental impact of conventional fuel usage, the prospect of producing clean and sustainable power in substantial quantities from RESs arouses interest around the world. Energy prices, supply uncertainties, and environmental concerns are driving the United States to rethink its energy mix and develop diverse sources of clean, renewable energy. The nation is working toward generating more energy from domestic resources that can be cost-effective and replaced or renewed without contributing to climate change or major adverse environmental impacts [6].

A technical report from National Renewable Energy Laboratory (NREL) has reported that there are significant reductions in net CO_2 emissions from plug-in hybrid electric vehicles (PHEVs) [7]. The combination of fluctuating high oil costs, concerns about oil security and availability, and air quality issues related to vehicle emissions are driving interest in PHEVs. The economic incentive for owners to use electricity as fuel is the comparatively low cost of fuel. Considering the cost advantage, a study by the Electric Power Research Institute (EPRI) found a significant potential market for PHEVs [8]. However, if vehicles are charged randomly, peak load will be very high and new power plants to meet this peak load needs to be installed, which is very costly. The electrification of transportation sector will need not only the re-structuring of present gasoline stations but also the modification of present power infrastructure.

The Government of United States has indicated placing one million plug-in hybrid vehicles (PHEVs) and electric vehicles (EVs) on the road by 2015 to reduce emission [9]. PHEVs and EVs cannot alone solve the emission problem completely, as they need electric power which is one of the main sources of emission. Therefore, success of practical application of PHEVs and EVs to achieve the goal of emission reduction greatly depends on the maximum utilization of renewable energy in smart grid. A smart grid should be adequate where

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Authors are with the Real-Time Power and Intelligent Systems Laboratory (http://rtpis.org), Missouri University of Science and Technology, Rolla, MO 65409-0040, USA (email: aysaber@ieee.org, gkumar@ieee.org).

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there is sufficient power supply to meet the load demand with minimum cost and emission. PHEVs and EVs with additional vehicle-to-grid capability and renewable energy sources in a smart grid can help in this issue. RESs are cheap (in terms of operation cost); however, they have problems of uncertainty, reliability and stability. Technologies to dynamically optimize the time varying resources such as RESs, gridable vehicles, etc. in a complex smart grid are essential. The authors of this paper make a bridge between electric power and transportation infrastructures through gridable vehicles.

PHEV and EV researchers have mainly concentrated on the interconnection of energy storage of vehicles and grid [10-16]. Their goals are to educate about the environmental and economic benefits of PHEVs and EVs, and to enhance the product market. However, power system reliability consists of system security and adequacy. Ideally, EVs should be charged from renewable sources, and gridable vehicles can act as small portable power plants (S3Ps). Besides, intelligent scheduling of S3Ps can reduce operation cost and emission.

The rest of the paper is organized as follows. In Section II, problem model is formulated for transportation and electric power sectors as linear model and non-linear model respectil

TABLE I
GENERATOR EMISSION CO-EFFICIENTS

Unit	α_i (ton/h)	β_i (ton/MWh)	γ_i (ton/MW^{2}h)
U-1	103.3908	-2.4444	0.0312
U-2	103.3908	-2.4444	0.0312
U-3	300.3910	-4.0695	0.0509
U-4	300.3910	-4.0695	0.0509
U-5	320.0006	-3.8132	0.0344
U-6	320.0006	-3.8132	0.0344
U-7	330.0056	-3.9023	0.0465
U-8	330.0056	-3.9023	0.0465
U-9	350.0056	-3.9524	0.0465
U-10	360.0012	-3.9864	0.0470

TABLE II
PLANT SIZE AND MAXIMUM CAPACITY (1,662 MW) OF 10-UNIT SYSTEM

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10
P_i^{max}(MW)	455	455	130	130	162	80	85	55	55	55
P_i^{min}(MW)	150	150	20	20	25	20	25	10	10	10

IV. RESULTS AND DISCUSSIONS

One million EVs are distributed to 20 cities where each city has (1,000,000/20=) 50,000 vehicles for simplicity of calculations. It is also more logical that all one million EVs will not be under one independent system operator (ISO) to charge (and discharge) and power system emission has non-linear characteristics for scaling. A standard ISO of 10-unit system is considered for simulation with 50,000 EVs. Load demand and unit characteristics of the 10-unit system are obtained from [20]. Emission coefficients and plant data are given in Tables I and II, respectively. Two models are investigated to show the effect of one million EVs on electric power and transportation sectors.

(i) Case 1 (load leveling model): EVs charge from conventional generation using load leveling optimization;
(ii) Case 2 (smart grid model): EVs charge from renewable sources and discharge to the grid.

Parameter values are -
total number of vehicles (assumed) of a city = 50,000; maximum battery capacity = 25 kWh; minimum battery capacity = 10 kWh; average battery capacity, P_v = 15 kWh; charging-discharging frequency = 1 per day; scheduling period = 24 hours; departure state of charge, Ψ = 50%; efficiency, ξ = 85%; for PSO, $SwarmSize$ = 30, no. of iterations = 1,000 and accelerating parameters c_1 = 1.5, c_2 = 2.5.

A. Load leveling model

For practical applications, number of EVs in an electric power network can be estimated analytically based on the number of electricity clients (customers) in that network. An estimate of gridable vehicles from residential electricity clients may be computed as follows:

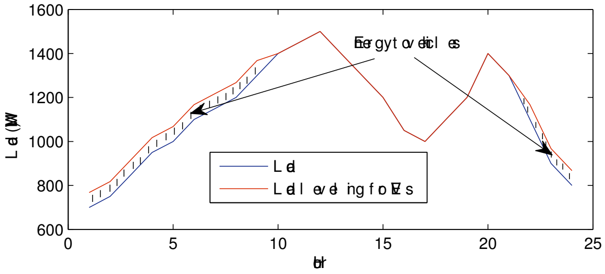

Fig. 1. Load leveling for EVs.

$$\begin{aligned} N_{GV} &= NV_{UC-V2G} V_{REC} N_{REC} \\ &= NV_{UC-V2G} V_{REC} X_{RL} L_{min} / AV_{HLD} \end{aligned} \tag{10}$$

$$AV_{HLD} = AV_{MEC} / (30 \times 24) \tag{11}$$

where:

N_{GV} = Number of Gridable Vehicles (GVs)
NV_{UC-V2G} = % of the number of registered GVs for participation in "UC with V2G"
V_{REC} = Average number of gridable vehicles per residential electricity client
N_{REC} = Number of residential electricity clients
X_{RL} = Percentage of residential loads in the power network
L_{min} = Minimum load in the power network at given time (MW)
AV_{HLD} = Average hourly load demand per residential electricity client (kW)
AV_{MEC} = Average monthly electricity consumption per residential electricity client (kWh).

For example: the minimum load, L_{min}, in the 10-unit benchmark system considered in this paper is 700 MW [20]. It can be taken that the average monthly electricity consumption, AV_{MEC}, of a domestic home is about 1,500 kWh [21]. Thus average hourly electricity load of a residential client, AV_{HLD}, is 2.0833 kW. Assuming that X_{RL}=30%, the total number of clients in the region N_{REC}, is 100,801.6 and it can be rounded to 100,000 for simplicity. It is reasonable to assume that in the future, in United States, V_{REC}=1, i.e. on average there will be one gridable vehicle per residential electricity client, and NV_{UC-V2G}=50%, i.e. 50% vehicles register to participant in the process. Thus, N_{GV} from (10) is about 50,000 and this is a reasonable number of vehicles to be considered on the 10-unit benchmark system for the simulation studies in this paper.

The average distance driven by a vehicle is about 12,000 miles per year [21] (32.88 miles per day). It is assumed that an EV can run 4 miles/kWh. Therefore an EV needs about 8.22 kWh (32.88/4) per day. Study on load forecasting including EVs are not done yet. So an approximate linear model is shown here. Total power needed for only 50,000 vehicles is (50,000*8.22Wh=) 411 MWh in a small system. If EVs are charged randomly from the existing power system, in the worst case peak load will be increased by 411 MW which is about 25% of maximum load of the system where there are 50,000 EVs from residential customers. It is logical that

TABLE III

EMISSION FROM 10-UNIT SYSTEM

Time (H)	U-1 (MW)	U-2 (MW)	U-3 (MW)	U-4 (MW)	U-5 (MW)	U-6 (MW)	U-7 (MW)	U-8 (MW)	U-9 (MW)	U-10 (MW)	Emission (ton)	Demand (MW)
H 1	455.0	244.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6827.0	700.0
H 2	455.0	295.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7547.2	750.0
H 3	455.0	265.0	0.0	130.0	0.0	0.0	0.0	0.0	0.0	0.0	7728.0	850.0
H 4	455.0	364.9	0.0	130.0	0.0	0.0	0.0	0.0	0.0	0.0	9448.6	950.0
H 5	455.0	285.0	130.0	130.0	0.0	0.0	0.0	0.0	0.0	0.0	8653.9	1000.0
H 6	455.0	385.0	130.0	130.0	0.0	0.0	0.0	0.0	0.0	0.0	10499.6	1100.0
H 7	455.0	410.0	130.0	130.0	25.0	0.0	0.0	0.0	0.0	0.0	11304.6	1150.0
H 8	455.0	455.0	130.0	130.0	25.0	0.0	0.0	0.0	0.0	0.0	12410.0	1200.0
H 9	455.0	455.0	130.0	130.0	104.9	0.0	25.0	0.0	0.0	0.0	12724.0	1300.0
H10	455.0	455.0	130.0	130.0	162.0	0.0	25.0	10.0	0.0	0.0	13326.1	1400.0
H11	455.0	455.0	130.0	130.0	162.0	0.0	25.0	55.0	35.1	0.0	13555.0	1450.0
H12	455.0	455.0	130.0	130.0	162.0	0.0	47.9	55.0	55.0	10.0	13872.9	1500.0
H13	455.0	455.0	130.0	130.0	162.0	0.0	25.0	10.0	0.0	0.0	13326.1	1400.0
H14	455.0	455.0	130.0	130.0	104.9	0.0	25.0	0.0	0.0	0.0	12724.0	1300.0
H15	455.0	455.0	130.0	130.0	25.0	0.0	0.0	0.0	0.0	0.0	12410.0	1200.0
15 H16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0		

TABLE IV

EMISSION FROM

TABLE V

SMART GRID SCHEDULE AND DISPATCH OF GENERATING UNITS AND GRIDABLE VEHICLES

Time (H)	U-1 (MW)	U-2 (MW)	U-3 (MW)	U-4 (MW)	U-5 (MW)	U-6 (MW)	U-7 (MW)	U-8 (MW)	U-9 (MW)	U-10 (MW)	V2G/S3P (MW)	No. of vehicles	Emission (ton)	Demand (MW)
1	455.0	230.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.37	2254	6649.2	700.0
2	455.0	280.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.24	2234	7325.9	750.0
3	455.0	249.1	0.0	130.0	0.0	0.0	0.0	0.0	0.0	0.0	15			

V. CONCLUSION

A linear approximate emission model for transportation sector and a non-linear more accurate model for electric power sector have been considered in this paper for estimating the impact of one million EVs on emission reductions. Load leveling model and smart grid model are investigated. From the simulation results, emission reduction is not guaranteed in the load leveling model. On the other hand, si