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Stochastic Model of Electric Vehicle Parking Lot Occupancy in Vehicle-to-Grid (V2G)

Santoshkumar[a], Udaykumar R.Y[b]*

[a,b] *Department of Electrical and Electronics Engineering, National Institute of Technology Karnataka, Surathkal - 575 025, India.*

Abstract

The Vehicle-to-Grid (V2G) is a concept of connecting group of electrical vehicles (EV) to the grid for power transaction. The EVs can get connected to the grid through the charging slots available in the electrical vehicle parking lot (EVPL). The Markov chain based stochastic model is proposed for EVPL occupancy in V2G for Smart Grid application.

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Keywords: Stochastic Model, Markov Chain; V2G.

1. Introduction

The EV can be integrated to the grid through home or other interface and contributes power to meet the grid requirements. EVs are usually parked for 90-95% of the time in residential apartment, office buildings and parking station [1]. EV connected to the grid through home interface is known as Vehicle-to-Home (V2H), EV connected to the other EV is known as Vehicle-to-Vehicle (V2V) and group of EVs connected to the grid is Vehicle-to-Grid (V2G). V2G can be used for peak shaving, valley filling, and load leveling. It also provides reactive power support to the grid and helps in maintaining grid stability [2]. EVs are parked in EVPL and get connected to the grid through the charging slot as shown in Fig.1.

* Santoshkumar Tel.: +91-9844027103; fax: +91-824-2474033.
E-mail address: santoshkumar.s.in@ieee.org

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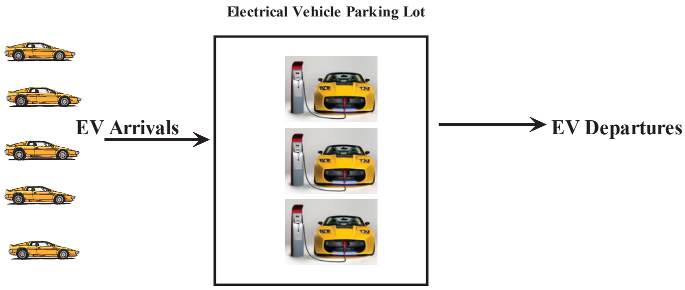

Fig.1. EV arrivals and departures in EVPL.

2. Stochastic Modeling of EVPL Occupancy

A Stochastic model based on Markov chain is developed for EVPL occupancy. Let X_n be the number of EVs in the system at time n, then $X_n \in S := \{0, 1, 2, 3, \cdots, L-1, L\}$ where, n is the time slot enough to transmit one EV, L is the size of the parking slot in number of EVs. EVs arrive at the parking lot with a probability a in time slot n. EV that arrives at time slot n is available to be forwarded in the next time slot n+1. The charging slot in the parking lot is involved in charging the other EV and allocates b for forwarding the EVs. As a consequence, the parking lot is able to forward EV with probability b in a given slot. With the probability of (1−b), the charging slot is performing task. The arrivals and departures are independent of each other [9, 10]. The proposed Markov Model for EVPL occupancy is shown in Fig.2.

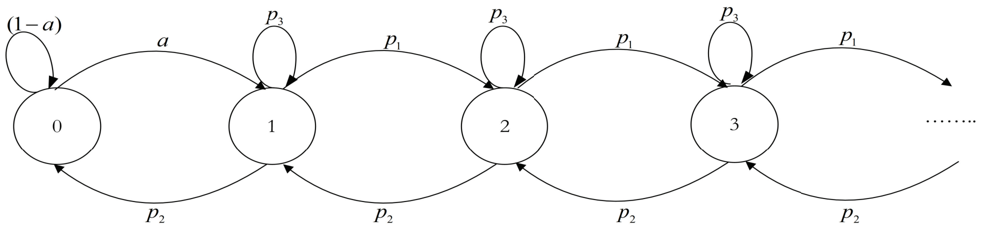

Fig. 2. Markov Model for Electrical Vehicle Parking Lot Occupancy.

2.1. Transition Probabilities

The state transition occurs when an EV arrives or departs. When an EV arrives at time n, the parking lot occupancy X_n either stays in the same state or moves to the next state based on the departure: $X_{n+1} = X_n$; if there is a departure in the same time slot and $X_{n+1} = X_{n+1}$; otherwise. Similarly, $X_n = X_n$; if there is no arrival in time slot n and $X_{n-1} = X_n$; otherwise.

$$p_{i,j} = \begin{cases} p_1 = a\,(1-b), & j = i+1,\ i = 1,2,....; \\ p_2 = (1-a)b, & j = i-1,\ i = 1,2,....; \\ p_3 = ab + (1-a)(1-b), & j = i,\ i = 1,2,...; \\ a, & i = 0,\ j = 1; \\ (1-a), & i = 0,\ j = 0; \\ 0, & otherwise \end{cases} \tag{1}$$

The balance equations are given by

$$\Pi = \Pi\ P \text{ and } \sum_i \pi_i = 1.$$

The balance equations are computed using :

$$\pi_0 .a = \pi_1 . p_2 ;$$
$$\pi_1 = \pi_0 .a + \pi_1 .p_3 + \pi_2 .p_2 ;$$
$$\pi_n = \pi_{n-1} .p_1 + \pi_n .p_3 + \pi_{n+1} .p_2 \; for\, n \geq 2 \tag{2}$$

Summing the first $n+1$ balance equations, we find that

$$\pi_n .p_1 = \pi_{n+1} .p_2 \; for\, n \geq 1 .$$

These equations are called the local balance equations.

The steady state distribution is given as

$$P_n = \frac{a}{p_2}\left(\frac{p_1}{p_2}\right)^{n-1} .P_0$$

where,

$$P_0 = \left(1 + \frac{a}{p_2} . \frac{p_2}{p_2 - p_1}\right)^{-1} \tag{3}$$

From the steady state distribution the average backlog $E[X]$ can be computed as

$$E[X] = \sum_n^{\infty} n.P_n \tag{4}$$

The transition probability p 0,1 from state 0 to 1 is a because there can be no departure when the charging slot is empty. The following are the assumptions [10] made while developing model:

i. Off-Board integrators which comply with IEEE 1547 standards for charging or discharging.
ii. The total time taken is considered as waiting time in queue plus the service time.

The discrete time birth and death process is considered.

3. Results and Discussion

The simulations are carried using MATLAB code. The results demonstrate that the utilization of the parking lot increases as the probability of EV arrival approaches the value of b as shown in Fig. 3. The Fig.4 depicts the average waiting time delay in hours as the probability of EV arrivals increases. For the probability of EV arrivals to be 0.85 the average delay in hours is 0.07 hours and depends on the EVs being connected to the charging slot. The Fig. 5 demonstrates the number of backlogs increase as the probability of EV increases. For EV arrival to be 0.9 the average number of EVs waiting is 7 and is obtained using equation 4.

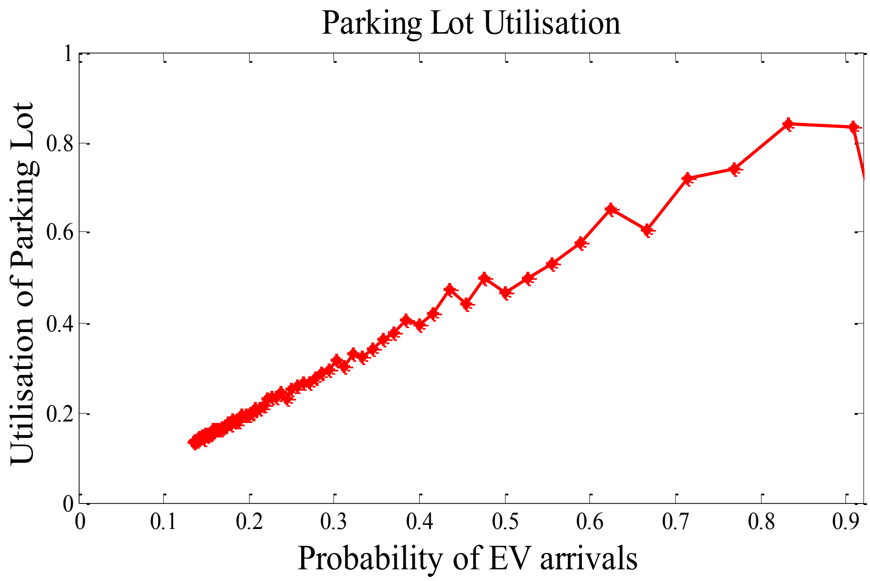

Fig.3. EVPL Utilisation.

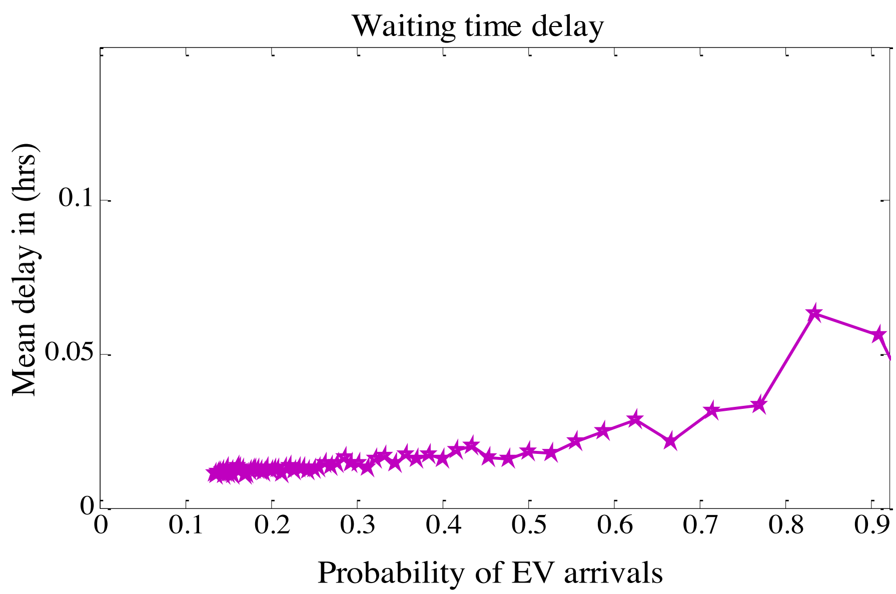

Fig. 4. Average waiting time in EVPL.

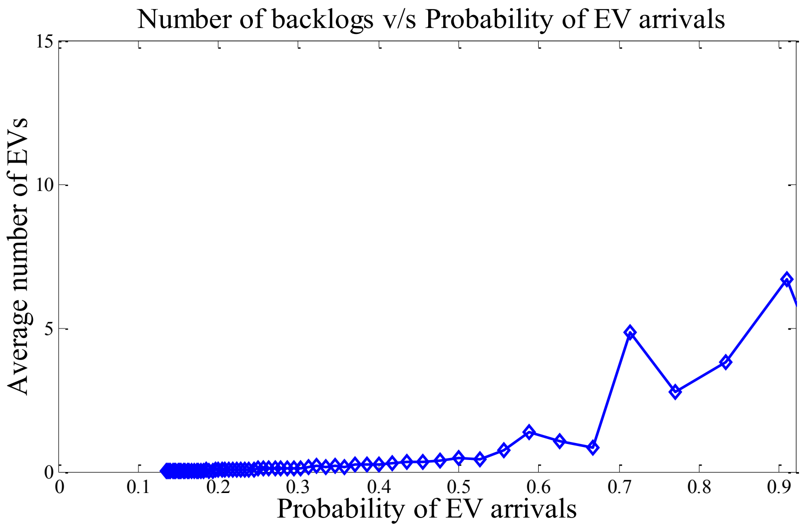

Fig.5. Number of Backlogs v/s Probability of EV arrivals.

4. Conclusion

A Stochastic model based on Markov chain is developed for EVPL occupancy and the simulations are carried out to estimate the charging slots in EVPL and the time required for EV to charge or discharge. Study on EVPL occupancy will help us to determine the number of EVs to be accommodated for charging or discharging.

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