Proceedings of 9th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2021 Month: March Volume: 9

Impact Analysis of Electric Vehicle with V2G and G2V Service in Distribution Network

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Abstract

With recent advancement in technology, Electric vehicle (EV) is the upcoming trend to get rid of air pollution and greenhouse gas emission. The market has a flourishing mission with the use of dual characteristics of EV. When EV comes up with additional demand on the network, the consideration of several factors with proper management there exist possibility of discharging of its stored energy back to the grid when required. This paper describes a U.K model of EV in which charging and discharging schedule is established taking into the account of the battery state of charge, time of day,and electricity prices. Applying empirical data, the network loss before and after EV penetration is analyzed with IEEE 33 bus network. The result shows that when charging station is considered as normal load station it has some impacts on Network in terms of loss and voltage profile, when the charging station is operated with modeled EV, i.e. in both V2G and G2V strategy network overall loss were minimized with improving voltage profile.

Keywords

Electric Vehicle, state of charge, power flow, vehicle to grid, grid to vehicle, Load flow

1. Introduction

Electric Vehicles (EVs) is a very essential component of power network in upcoming future. Electric vehicles use batteries as an energy storage device to supply power to their electric motor. Batteries of EVs can be used as flexible loading device like load, generator or storage. Growing use of Electric Vehicle could eradicate being a solution to both the global fossil fuel crisis and the problems of environmental and climate change [1].

For energy storage technology, Vehicle to Grid (V2G) theory suggests the exchange of two way power flow between electric vehicles battery and the electric power network. Discharging and charging modes of operation of EVs Batteries occur when such technology is implemented to any grid connected Electric Vehicle. G2V is known as Charging mode and V2G is known as discharging of battery [1]. EV batteries can be used as renewable energy storage device with V2G concept to handle uncertainty present in generation [2]. G2V mode of EV is taken as a load to distribution network. EV may discharge its stored energy from its battery to the grid in V2G mode. The V2G concept assists the owner of the EV to make revenue through the grid sale of electricity at the time when the electricity cost is high and when EVs are connected to charging plug [1].

The loads for electric vehicles during charging are a new form of load in the power distribution network. These charging currents of EVs depends primarily on the driving actions of the individuals (arrival & departure schedule time and distance they traveled). Public driving activity is an inherently spontaneous phenomenon. Thus, the overall demand for charging in a specific power system is entirely unknown. But the better management of these can provide lots of advantages for the distribution network such as peak load saving & shifting, power loss and total cost reduction [3]. However, such technological problems are placed due to the lack of smart management strategies for EVs in the smart grid, such as increased system losses, system congestion, transformer and line overloading, declining power quality and reliability [3]. The management, planning and maintenance of the power system with the heavy use of EVs is becoming more complicated because of these factors. We may use the electric vehicle battery as an energy storage unit utilizing the V2G feature of electric vehicles. The owner of EVs will benefit from the V2G capability by selling its stored energy from battery to the grid when the price of electricity is high. This paper discusses on techno economic benefits of effective utilization of controlled charging and discharging of parked Electric Vehicle batteries. A simulation of 12.66 kV, IEEE 33 bus system has taken into consideration and impacts of EV parking station in network during different conditions of Station during a day are studied. Power dispatch strategies are developed taking into account of the state of charge of battery, vehicle users driving behavior and the electricity buying and selling prices. With application of these strategy the EVs can be used to act as a generation sources or as a responsive loads [4].

2. Battery Characteristics

State of charge of any battery (SoC) with reference to its capacity at a constant discharge current is given by,

$$Soc(t) = 1 - ((I_d * h)/(3600 * C_a)) \quad (1)$$

where,
I_d discharge current in Ampere,
C_a available capacity in Ampere hour,
h time in second.
Available capacity of the battery with the peukert equation is modeled as,

$$C_a = (I_d * C_p)/(I_d^k) \quad (2)$$

where,
C_p Peukert capacity of battery in Ampere hour,
K Peukert exponential (1.1-1.3).
Both K and C_p are fixed parameters for a given battery. The Peukert capacity, C_p is formulated as,

$$C_p = T * (C^N/T)^k \quad (3)$$

where,
C^N nominal capacity in Ampere hour Ah,
C^N/T nominal discharge current in Ampere (A).
The value of the Peukert exponent in 2 and 3 can be extracted from an experimental test for a particular battery [5], and the lower the Peukert exponent, the better the battery efficiency (k=1 is used to model the ideal battery). The available capacity decreases from 158.5 Ah to 87.1 Ah for a battery rated at 100 Ah for 5 h discharge time and a Peukert exponent of 1.2, as the discharge current increases from 0.1 C/5 (2 A) to 2 C/5 (40 A), as shown in the figure1.

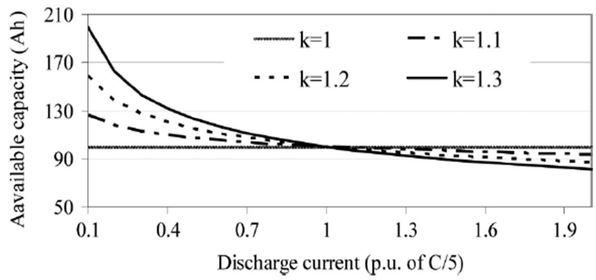

Figure 1: Effective battery capacities at different discharge current, 100Ah at 5h [4]

Table 1: Lookup the battery voltage versus released capacity, 240 Volts and 100Ah, Lead-Acid battery Type [4]

Charge/ Discharge Current		Voltage(V) at Release Capacity(Ah)				
p.u.	A	0	20	60	80	100
0.1	2	259.4	244.6	237.5	225.4	123.2
...	...	...	...	...	...	...
0.5	10	258.9	244.2	237	224.8	122.8
...	...	...	...	...	...	...
1.5	30	257.7	243	235.8	223.7	121.6

Table1 data is interpolated to derive the voltage corresponding to the updated SoC value, based on the selected discharge current i_d, at the start of the current time interval t, S_{t-}. Because of the value of S_{t-}, the power released before t_-, C_{t-} can be obtained from (1). Interpolation is then carried out to obtain the voltage value, V_{t-}, based on the value of C_{t-}. The discharge/charge power of the EV is obtained with the voltage V_{t-} and current I_d, where the value of V_{t-} is assumed to be constant over a fixed time interval [4].

3. Power Flow Model With EV Batteries

In electric vehicles, the energy stored is limited by the state of charge and by the driving requirements of the vehicles. The energy used in electric vehicles on road is considered to be constant at a value of 20 A due to the actual driving duty cycles for EVs.

The S_{min} and S_{max} limit values in this paper are set at 0.1 and 0.9 p.u, respectively. In order to ensure that the battery SoC maintains between S_{min} and S_{max} while the vehicle is connected to the grid, discharge and charge strategies need to be configured so that at the end of the current time interval, the amount of power to be dispatched in any given time span does not violate the SoC mark [4].

In Figure 2
S_{t+} and S_{t-} SoC values at the beginning and end of the current time interval t, respectively.
i_t charge or discharge current of the EV during the time interval t.
C_{t-} release capacity from initial time to final time point t-.

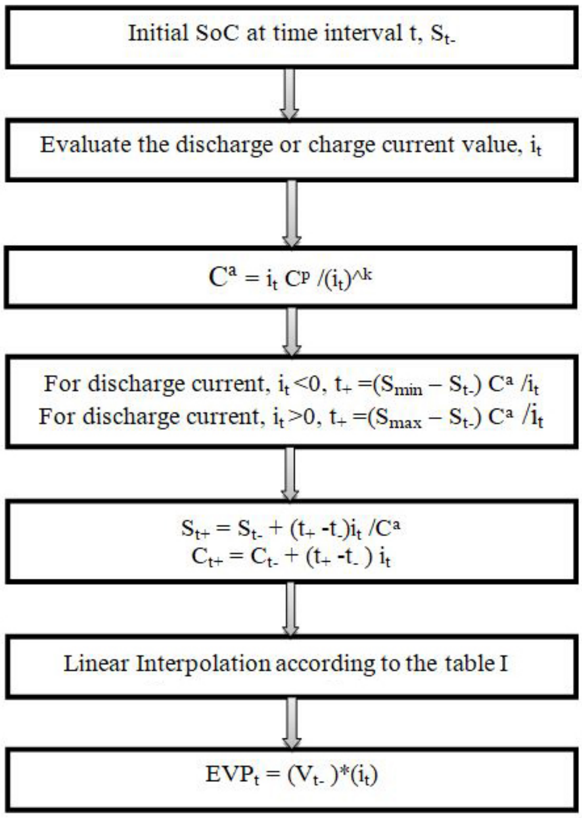

Figure 2: Flowchart for extracting the battery storage power [4]

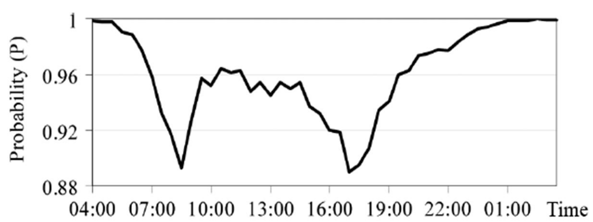

Figure 3: Probability of not using private cars for commuting on a weekday [6]

An analysis of the feasibility that a private car will be parked during a weekday, shows a feature of the driving profile which indicates two dips from 07:00 to 09:00 during traffic rush hours and from 17:00 to 19:00 when most trips occur [6]. The model utilizes the probabilities when measuring the number of parked cars that can be interconnected with the power grid [4].

4. Battery Storage Power Dispatch Strategies

Battery SoC must remain within minimum and maximum value of SoC when vehicle get connected to grid. Some better strategies needed to control value of SoC in different timing. Step of half hour has been chosen to reflect the time step of current British Electricity Trading and Transmission Arrangements (BETTA) [7]. Discharge/ charge current, depending on three set of rules are used for predefined V2G operations, with considering state of Charge of the EVs and the half hourly electricity rates [4].

Rule set 1:
During the current time period t, the following rule is set for the electric vehicle, EVRt is:

```
if (SoC >= 0.75)
    EVRt = -1 (discharge)
else if( SoC <= 0.5)
    EVRt = 1 (charge)
else
    EVRt = 2 (undetermined)
```

Rule set 2:
In order to determine whether a vehicle is in principle usable for V2G operation, an enable (1)/disable (0) control signal (CS) from a third party such as an EV aggregator is added [4]. In Rule Set 1, V2GRt depends on both the control signal, CS and SoC as if a vehicle is currently available for a V2G role during the current time span t.

```
if (EVRt == -1)
{
    if (CSt == 1)
        V2GRt = -1 (V2G Service)
    else,
        V2GRt = 0 (Block off)
}
else if (EVRt == 1)
    V2GRt = 1 (Charge)
else if (EVRt == 2)
```

```
{
    if (CSt == 1)
    V2GRt = 2 (Undetermined)
    else,
        V2GRt = 0 (Block off)
}
```

Rule set 3:
The final rule used to pick the discharge/charge current level in the t-period represents the prevailing price as follows:

Day time (from 08:00 to 00:00)

```
if (V2GRt == 1)
{
    if (bprt >= hbpr),
      it = IL ;
    else,
      it = IH;
}
else if(V2GRt == -1)
{
   if (sprt >= hspr),
     it = - IH ;
   else,
     it = - IL;
}
else if(V2GRt == 2)
{
   if (bprt <= hbpr),
     it = IH;
   else if (sprt >= hspr),
     it = - IM;
   else,
     it = - IL;
}
```

Night time (from 00:30 to 07:30)

```
if(V2GRt ==  1)    it =  IL
if(V2GRt == -1)    it = -IL
if(V2GRt ==  2)    it = -IL
```

where,
IL, IM, IH low, medium, and high levels of the currents.
+/- sign specify the charge and discharge role;
bprt, sprt buying and selling price of electricity price during current time period t, respectively.
hbpr, hspr high buying and selling price, respectively.
Rule Set 3 is intended to take into account the potential for price arbitrage, charging the EV at the high current rate when prices are low and discharging when prices are high (and if the V2G service is enabled) [4].

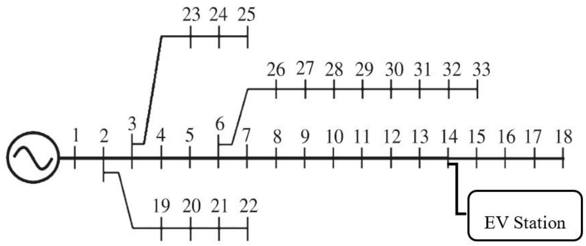

Figure 4: IEEE 33 bus network with EV Station

In the Figure 4 electric vehicle station is at bus 14. There are 100 vehicles on that station. The power flow constraint of distribution network should meet. Limit of state of charge (SoC) of electric vehicle battery should not be violated.

$$SoC_{min} <= SoC_k <= SoC_{max}$$

Where,
$SoC_{min/max}$ minimum/maximum limit of battery state of charge.
SoC_k state of charge of k^{th} EV battery.

5. Numerical Studies

Analysis on IEEE 33 bus network is considered with EV energy storage model. This system contains 32 branches, all of which have switches installed. The base MVA is set to 100 MVA and the base voltage is 12.66 kV [8]. Table 2 lists the characteristics of the EV batteries and applies them to each individual EV. The three options for the charge/discharge currents used in rule set 3, IL, IM and IH, in Table 2, can be described as 0.1 C/5 (2A), 0.5 C/5 (10 A) and 1.5 C/5 (30 A), where the rated capacity is denoted as C [4]. The driving pattern of any vehicle is not well known. It varies from time to time, day to day and is seldom fixed. Each user is quite distinct in his/her driving pattern. There are not even two user with similar driving profiles, even for a very small fraction of the time. While each vehicle would have its own driving profile, by considering a large number of vehicles, we describe a particular driving profile without visible error. Figure 5 shows the three profiles of electric

Table 2: EV Battery Characteristics [4]

Battery Type	Rated Capacity (Ah)	Rated Hours	Peukert Exponent	Nominal Volatage (V)	Peukert Capacity (Ah)	Discharge/ Charge Current p.u. of C/5	Effective Available Capacity(Ah)
Lead Acid	100	5 h	1.2	240	182.06	0.1	158.5
						0.5	114.87
						1.5	92.21

vehicle among which one is assumed to take the EV on-road profile for one day. Each profile is based on the total number of 1000 on-road vehicles and the probability that P will be parked, as shown in Figure 5 [4].

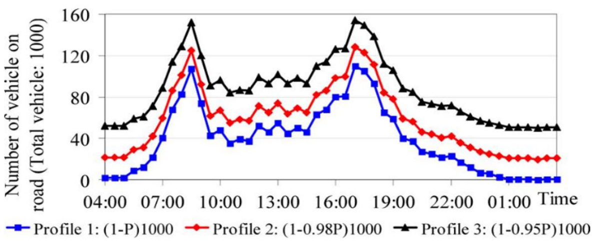

Figure 5: Three profiles of electric vehicles on road during one day [4]

The Adjusted System Selling Price (ASSP) and Adjusted System Buying Price (ASBP) values, as shown in Figure 6, was implemented to represent both wholesale electricity prices and domestic tariffs when calculating payments to and from the operator when the EVs are charged or discharged from the grid [9]. The values of the SSP and SBP are taken from [9]. The high ASSP price level (£0.172/kWh) is set at 90% of the maximum ASSP (£0.191/kWh), while the high ASBP price level (£0.147/kWh) is set at 60% of the maximum ASBP (£0.245/kWh) [1]. It should be noted that ASSP and ASBP values are defined on the operator's side of the power system. These two values swap sense as the discharging energy price (selling, ASBP) and the charging energy price (buying, ASSP) in estimating the payments to the EV and in applying decision rule set 3 as presented in section above [4].

5.1 Electric vehicles charging/discharging strategy

The electric vehicles are charged and discharged according to the rules stated in the methodology section. The rules are based upon the initial state of charge (SoC), real time electricity prices and charging requirements of vehicles. The variation of state of

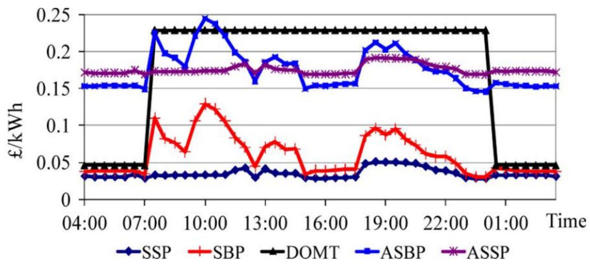

Figure 6: Price profile during one day (SSP/SBP: system selling/buying price, DOMT: domestic tariff, ASSP/ASBP: adjusted system selling/buying price [9]

charge (SoC), charging/discharging status of an electric vehicle having initial SoC of 0.68 at 4:00 am when charged and discharged according stated rules is presented in Table3. The graph of variation of SoC during 24h of time starting from 4:00 am is presented below in Figure 7. The data of charging and discharging current, power, electricity buying and selling rates for each half an hour of time are presented in Table 3.

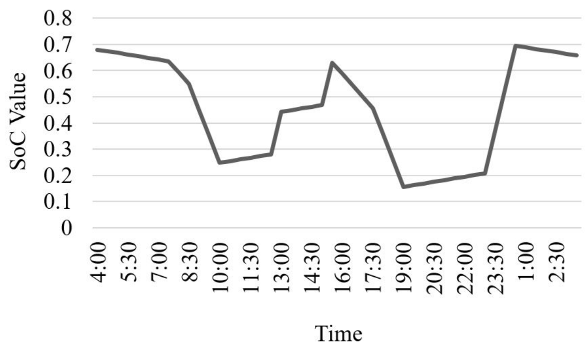

Figure 7: SoC variation of EV during 24 hr

5.2 Network loss after EV penetration

In the Figure 8 the horizontal straight line indicate the network loss value of base case i.e. IEEE 33 bus network where no any electric vehicle load has considered. Network loss for base case and losses when EV is on road is of same value i.e. 202.6361 kW, it's because when EV is on road it neither gives

Table 3: Battery Energy Storage Status of EV1

S. No.	Time	Electricity buying price (Ł/kWh)	Electricity selling price (Ł/kWh)	SoC of battery	Discharging current (A)	Status
1	4:00	0.172	0.153	0.68	-2	V2G (2A)
2	4:30	0.171	0.153	0.6737	-2	
3	5:00	0.171	0.154	0.6674	-2	
4	5:30	0.171	0.154	0.6611	-2	
5	6:00	0.171	0.154	0.6548	-2	
6	6:30	0.174	0.154	0.6485	-2	
7	7:00	0.169	0.149	0.6421	-2	
8	7:30	0.173	0.225	0.6358	-10	V2G(10A)
9	8:00	0.173	0.198	0.5923	-10	
10	8:30	0.173	0.192	0.5488	-20	On Road
11	9:00	0.173	0.179	0.4488	-20	
12	9:30	0.173	0.221	0.3488	-20	
13	10:00	0.174	0.245	0.2488	2	Charging (2A)
14	10:30	0.174	0.238	0.2551	2	
15	11:00	0.174	0.221	0.2614	2	
16	11:30	0.18	0.198	0.2677	2	
17	12:00	0.183	0.186	0.274	2	
18	12:30	0.17	0.16	0.2803	30	Charging (30A)
19	13:00	0.182	0.186	0.443	2	Charging (2A)
20	13:30	0.176	0.193	0.4493	2	
21	14:00	0.176	0.183	0.4556	2	
22	14:30	0.176	0.184	0.4619	2	
23	15:00	0.17	0.15	0.4682	30	Charging (30A)
24	15:30	0.169	0.154	0.6309	-10	V2G(10A)
25	16:00	0.169	0.154	0.5874	-10	
26	16:30	0.17	0.155	0.5439	-10	
27	17:00	0.17	0.156	0.5003	-10	
28	17:30	0.171	0.157	0.4568	-20	On Road
29	18:00	0.189	0.202	0.3568	-20	
30	18:30	0.191	0.212	0.2568	-20	
31	19:00	0.191	0.203	0.1568	2	Charging (2A)
32	19:30	0.191	0.211	0.1631	2	
33	20:00	0.19	0.197	0.1694	2	
34	20:30	0.189	0.189	0.1757	2	
35	21:00	0.185	0.177	0.182	2	
36	21:30	0.18	0.173	0.1884	2	
37	22:00	0.179	0.173	0.1947	2	
38	22:30	0.176	0.164	0.201	2	
39	23:00	0.17	0.15	0.2073	30	Charging (30A)
40	23:30	0.169	0.146	0.3699	30	
41	0:00	0.169	0.146	0.5326	30	
42	0:30	0.174	0.158	0.6953	-2	V2G (2A)
43	1:00	0.173	0.156	0.689	-2	
44	1:30	0.174	0.154	0.6827	-2	
45	2:00	0.174	0.154	0.6764	-2	
46	2:30	0.174	0.152	0.67	-2	
47	3:00	0.173	0.153	0.6637	-2	
48	3:30	0.172	0.153	0.6574	-2	

V2G services nor G2V services.

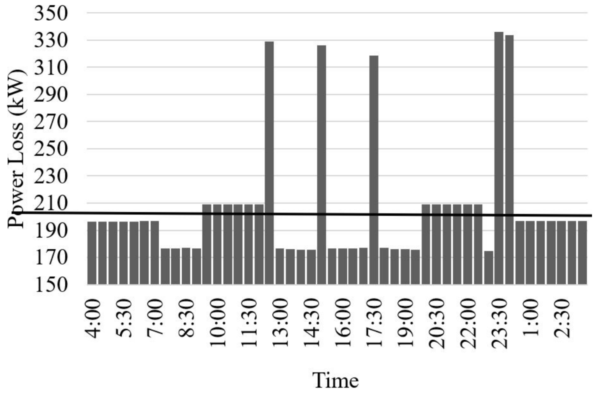

Figure 8: Network loss at EV station

Minimum network loss is achieved when EV provides V2G service of 10 A current which is about 174.7136 kW around 13.78% less than system base case loss and maximum loss is achieved when battery of EV is charging with high current of 30 A whose value is 336.29 kW. This is because increase in charging load which makes distribution network overload to some extent then it is in the base case load flow.

5.3 Voltage of IEEE 33 bus network after EV penetration

Figure 9 shows the voltages profiles of 33 bus network after EV integration at bus 14,at different operating modes of Electric Vehicles i.e. V2G service of 2A, V2G services of 10 A, Charging with 2A and charging with 30 A and of base case. Voltage profile for base case and on road case is same. The Lowest voltage condition is obtained when the EV is charging with high current(30A). Better voltage profile is obtained when EV operates with V2G services. V2G service of 10A resulted in low network loss than V2G service 2A

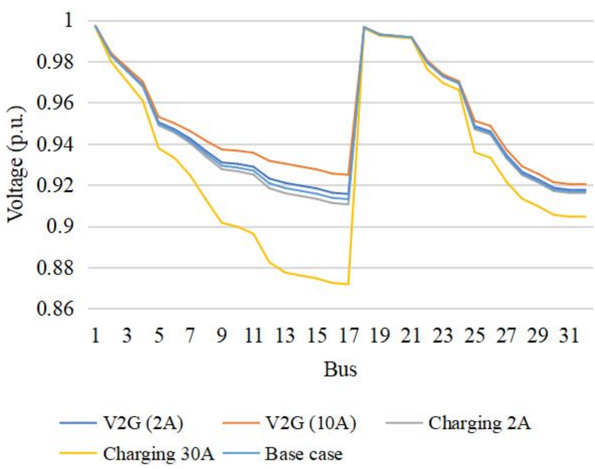

Figure 9: Voltages at bus in different modes

6. Conclusion

In addition to its primary transport applications, electric vehicles can also be used for the distribution network support while they are in the parking station as a rapid response load (G2V), or even a power source (V2G). Considering the charging and discharge cycles, the algorithms for energy storage deployed for electric vehicles have been developed and a set of decision strategies based on battery power characteristics, electricity prices and vehicle characteristics has been successfully developed and implemented in IEEE 33 Bus distribution network to perform power system analysis like Load Flow (LF) to observe the effect of EV integration.

After EV integration in IEEE 33 bus system the minimum network loss is achieved when EV provides V2G service of 10A current which is about 174.7136 kW around 13.78% less than system base case loss and maximum loss is achieved when battery of EV is charging with high current of 30A whose value is 336.29 KW.

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