Operating efficiency measurement and maximization for AC, DC and V2G charging technologies

ABSTRACT

EV charging technologies could improve grid flexibility, reduce the charging infrastructure need, and increase revenues when their operating efficiency is higher. This digest presents a single method to measure AC, DC, and V2G charging operating efficiency using different EV models. The common trend for all the charging technologies and EV models is their low efficiency at lower charging power. The operating efficiency is lower than 85% when operating at lower than 25%-40% of the nominal power in AC charging. In DC charging, the efficiency is around 85.21%-89.41%. In V2G charging, the efficiency is lower than 85% when operating around 10% -15% of the nominal power. The charging efficiency (89.23%) is better than the discharging one (85.31%), while the round trip efficiency is 76.12 %.

1. INTRODUCTION

As the number of EVs and charging technologies started increasing, understanding the impact of EV charging efficiency under different operating conditions is becoming more crucial. Only maximum efficiency values measured under a single operating condition are often reported by charging technology manufacturers. However, the real operating efficiency values depend on the operating conditions, and they are affected by the smart charging control and the EV BMS [1-2]. Therefore, measuring the operating efficiency of AC and DC charging technologies for different EV models under a real testing environment is important. Currently, few EV models in the industry possess V2G capability but next-generation models are expected to enable this capability [3]. Hence, V2G operating efficiency is also relevant.

Earlier experimental works on EV charging measurement reported charging efficiency in AC and DC charging [4-6]. An average of 85.7% charging efficiency using 1.9 kW and 3.8 kW AC chargers was measured with, the lowest value being 74.2 % using the 1.9 kW charger [4]. Ref [5] reported an average efficiency ranging from 83.6% to 87.2% (3kW-50kW) for DC charging. Authors in [6] presented an average efficiency of 60-85% depending on the operating charging power and the EV model. The negative impact of low power charging can be seen in all these measurements.

While all these measurements are based on AC and DC charging technologies, the efficiency of V2G has recently been a focus of some research works, as V2G efficiency can significantly affect grid services. The average round trip is around 79.2%-87.8%, with the charger losses being the highest of all the components. The general conclusions are that the charging efficiency is higher than the discharging, and the efficiency is lower (73.11%) at lower charging power (2.4 kW) [7-9].

More recently, new EV models and EV internal losses were measured in [10-11]. A charging efficiency of around 12.79-20.42 % and its impact on CO2 emissions and building consumption [12] and energy demand profile [13] were published. This digest presents a single method to measure the operating efficiency of different EV models using AC, DC, and V2G charging technologies under a real testing environment.

2. MEASUREMENT SETUP AND RESULTS

The testing setup for measuring the operating efficiency of different EV models using three charging technologies (AC, DC, and V2G) is depicted in Fig.1. Table 1 shows the EV model specifications. Measurement devices were installed in the chargers (AC side) and the EV battery (DC side). The EV charging and discharging efficiencies are calculated based on the below equations using the measurement datasets. More details for each charging technology are given in the following subsections.

$$P_{AC} = V_{AC} \times I_{AC} \quad (1)$$

$$P_{DC} = V_{DC} \times I_{DC} \quad (2)$$

$$\eta_{CH} = 100 \times \frac{P_{DC}}{P_{AC}} \quad (3)$$

$$\eta_{DCH} = 100 \times \frac{P_{AC}}{P_{DC}} \quad (4)$$

$$\eta_{RT} = \eta_{CH} \times \eta_{DCH} \quad (5)$$

With P_{AC}, V_{AC} and I_{AC} the voltage, the current and the power on the AC side respectively, P_{DC}, V_{DC} and I_{DC} the voltage, the current and the power on the DC side respectively, and η_{CH}, η_{DCH}, and η_{RT} the charging, the discharging and the round trip efficiency respectively.

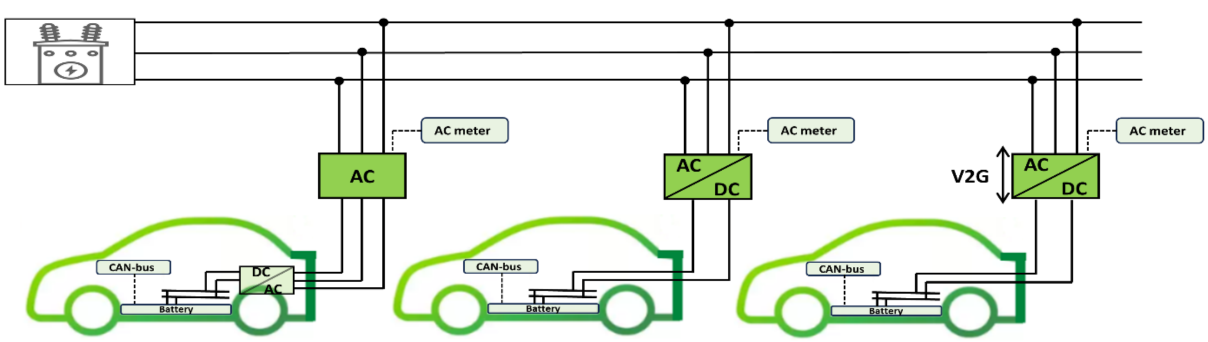

Fig. 1 EV charging efficiency measurement setup

TABLE 1: EV specifications

EVs	Battery capacity (kWh)	Milage (km)	SoH (%)	AC power (kW)	DC power (kW)	V2G
EV1	24	132000	73.8	1.3-6.6	46	Yes
EV2	24	120000	77.71	1.3-6.6	46	Yes
EV3	40	122000	86.9	1.3-6.6	50	Yes
EV4	46	39000	92.87	1.3-7.4	150	No
EV5	25	165000	83	4.4.-43	No DC	No
EV6	58	28000	99	4.1-11	170	No

A. AC charging

The AC power analyzer is used to measure voltage and current from the AC chargers, controlled via the Open Charge Point Protocol to send different power charging signals. The battery voltage and current datasets are collected via the CAN-bus (OBD 2 device) as shown in Fig 1. The minimum possible allowed power level is decided by the EV BMS for each EV model as indicated in Table 1. Therefore, the efficiency values which are calculated based on the equation (3) are plotted from the minimum to the maximum possible power as shown in Fig 2.

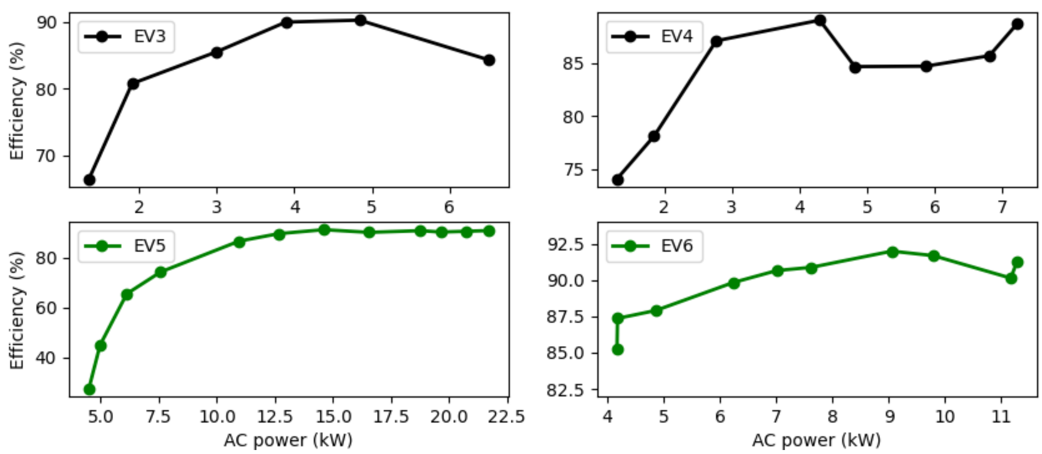

Fig. 2 AC charging efficiency

The charging efficiency of EV models is different, but they are all lower when operating at low charging power, which is often the case in smart charging control. The efficiency is lower than 85% when operating lower than 40% (EV3, EV4) and 25% (EV5) of the nominal power. However, the efficiency of EV6 (new model) is higher than 85%, even at the lowest possible charging power (4.1 kW, around 40% of the nominal power). Some EVs (EV3, EV4, EV6) have slightly lower efficiency when reaching their nominal power.

B. DC charging

The DC charging testing setup is shown in Fig 1, where the charger is a 50 kW off-board power converter. Similar measurement devices are used to collect datasets from EV2 and EV3 in the same testing environment and on the same day. The charging power in DC charging depends on the SoC of the EV. Therefore, the efficiency values are plotted from 55% to 85% SoC for EV2 and EV3, as depicted in Fig 3. The charging efficiency values are again lower when operating at a lower charging power level. The average efficiency in this test is 85.21% for EV2 and 89.41% for EV3. More DC charging sessions are required to compare these values fairly with AC charging.

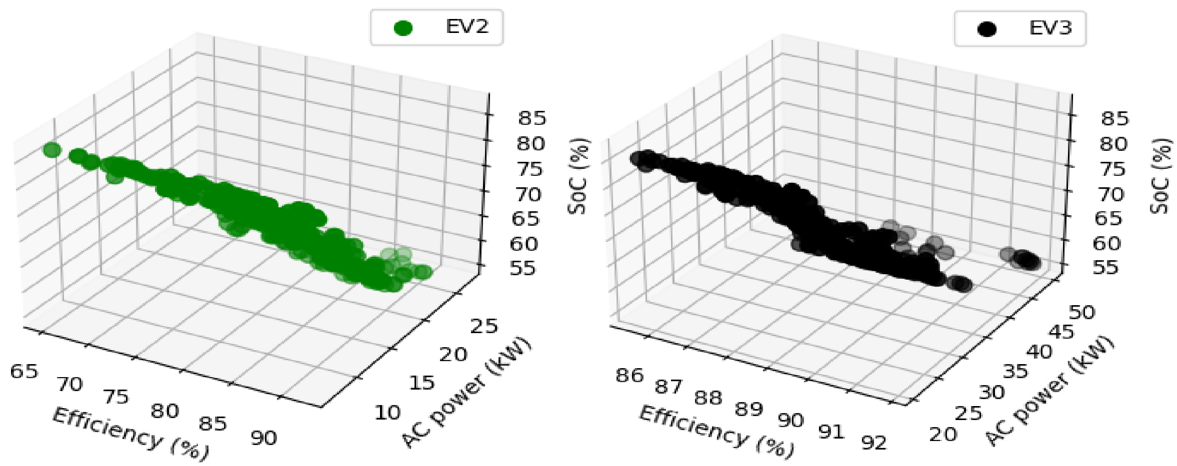

Fig. 3 DC charging efficiency for EV2 and EV3

C. V2G charging

For V2G charging, the charger used is a 10 kW bidirectional off-board power converter, as shown in Fig 1. Measurement datasets are collected from V2G-compatible models (EV2, EV3). This test was also performed in the same environment and on the same day for both EVs. Both EVs' SoC was around 50%, a stable region for most EV battery technology. The charging power in V2G charging can be lower than 5% of the nominal power. Therefore, the efficiency values are plotted from lower power charging levels compared to the AC and DC charging.

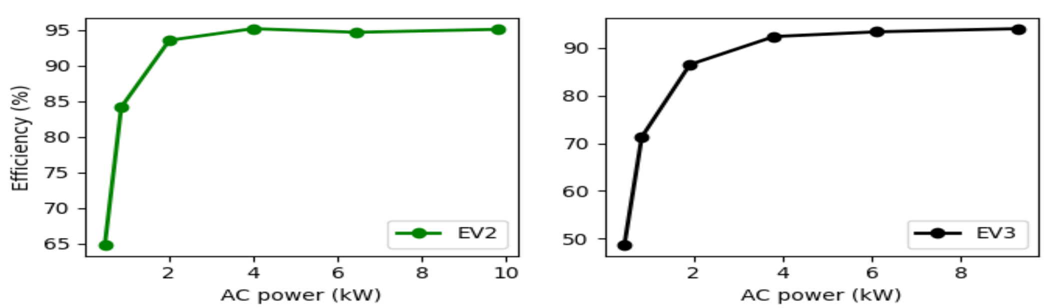

Fig. 4. V2G charging efficiency for EV2 and EV3

As shown in Fig 4, the charging efficiency is lower than 85% when operating around 10% (EV2) and around 15% (EV3) of the nominal power (10 kW). V2G charging and discharging scenarios between 65%-82% of the EV2 SoC with constant power (6.6 kW) are depicted in Fig. 5. Even with slightly lower average charging power, the charging scenario (89.23%) is still more efficient than the discharging scenario (85.31%). The average round trip efficiency is 76.12 %, demonstrating the importance of keeping higher operating efficiency, particularly in V2G charging.

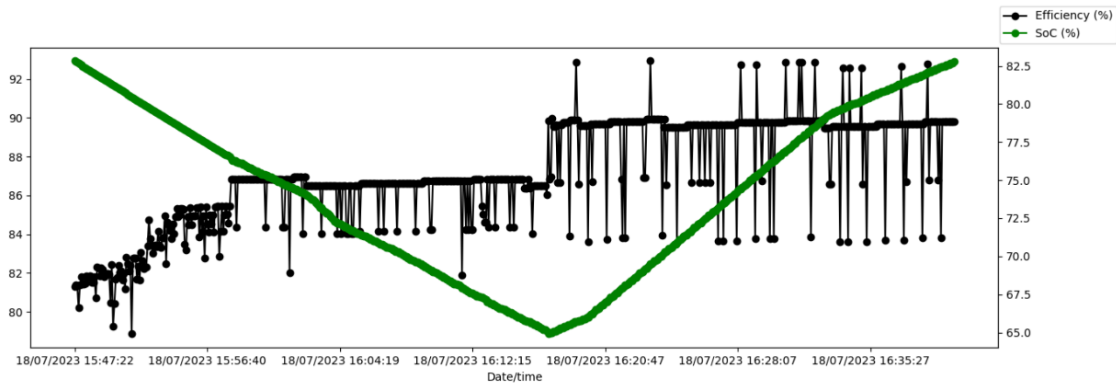

Fig. 5 V2G charging and discharging scenarios for EV2

3. DISCUSSIONS

To measure more realistic operating efficiency, places where all the used EV models are usually parked, serve as the testing environment. In AC charging, the operating efficiency is lower than 85% when operating at lower than 25%-40% of the nominal power. In DC charging, the efficiency is 85.21%-89.41%. More DC charging sessions are required to fairly compare with AC charging using the same charging power level. In V2G charging, the efficiency is lower than 85% when operating around 10% - 15% of the nominal power. The charging efficiency (89.23%) is better than the discharging one (85.31%). The average round trip efficiency is 76.12 %, and the power charging level can still operate around 5% of the nominal power. Therefore, finding and controlling the charging in the low efficiency zone (LEZ) and the high efficiency zone (HEZ) for each charging technology can minimize energy losses, particularly in AC charging.

4. CONCLUSIONS AND FUTURE WORK

A single method to measure the operating efficiency of different EV models using AC, DC, and V2G charging technologies using different EV models under a realistic testing environment is presented in this digest. The general conclusions include: Low operating efficiency for all the charging technologies at low power charging; Better DC charging (DC and V2G) efficiency than AC charging; Possibility of lower power charging in V2G and low round trip efficiency.

The full paper will give all the experimental results and a comprehensive table showing the main contributions of the present work compared to the existing similar research. Additionally, research works on optimizing the converter design [14] and several ways to maximize the operating efficiency for AC, DC, and V2G charging will be shared. Furthermore, control and monitoring strategies to identify LEZ and HEZ for each charging technology under the main operating conditions for each EV model will be elaborated in the full paper.

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