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Experimental Setup and Testing of a Lab-scale Off-grid Electric Vehicle Charging Station

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Abstract

This work presents a lab-scale demonstrator setup to develop a grid-independent electric vehicle (EV) charging station powered fully by renewable energy. The experimental is a 1/100th scale of the required renewable generation, energy storage system and EV charging load profile estimated for on a visitor attraction location in southeast of England as a case study. The paper describes system components, discusses the approach used to emulate renewables generation and presents the model used to predict the EV charging load. The analysis shows that the system can meet the scaled EV charging load demand during the day, and that the battery mainly needs to provide energy during the first period early in the day. The results of simulating a full year of charging station operation by the lab-scale demonstrator using time-accelerated experimental analysis suggest that lower renewables generation can reduce the cost of the system without affecting the efficacy of the charging station to cover the EV load.

Keywords: Electric vehicles, charging infrastructure, off grid, demonstrator.

1 Introduction

1.1 Background

The number of electric vehicles (EVs) is expected to grow in the United Kingdom (UK), driven by government policies that mandate the reduction of the transport sector emissions [1]. As the number of EVs grows, the rise in charging infrastructure is projected to increase rapidly to meet the charging demand [2]. Deploying the appropriate charging infrastructure requires following a plan that takes into consideration the behaviour of EV drivers and the environment where stations are to be located to reduce cost costs and meet consumer needs [3]. Nevertheless, deploying charging stations requires a grid connection, which can be expensive and may place additional strain on the grid [4, 5]. Charging EVs from renewable sources has the potential to accelerate decarbonisation. The ‘Future Electric Vehicle Energy networks supporting Renewables’ (FEVER) project aims to design a grid-independent charging station powered fully by renewables.

The small size and low cost of a scaled down demonstrator to act as a testbed before full implementation and increases the flexibility of installing and testing multiple components and functions before full scale development and field deployment [6]. This paper presents the first part of several planned tests of the development of demonstration systems as part of the FEVER project [7] to ensure reliable, efficient and cost-effective off-grid charging stations, as they play a vital role in increasing consumers' confidence in EVs. This work covers the first FEVER demonstrator as a lab-scale version describing system components, presents the model to predict the EV charging load and discusses the approach used to simulate renewables generation, including results from size-scaled and compressed time experimental testing to give insights into the operation of the full demonstrator.

1.2 FEVER Demonstrator

A plan of deploying several FEVER demonstrators at different scales is currently being developed, starting from a 1/100th lab-scale version in Southampton, as shown in Fig. 1. The target plan aims to provide verification and validation methods of the suggested approaches and technologies. The demonstrators offer a test bed for setting up and testing system components, connections, system control and communications. The work will also extend to support experimental analysis of hybrid energy storage systems combining different battery chemistries and other energy storage technologies.

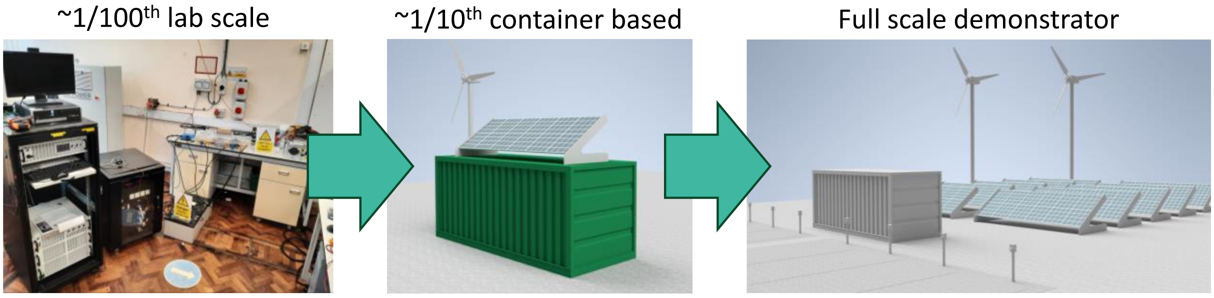

Figure 1: Target plan for the FEVER demonstrator.

2 Lab-scale Demonstrator Setup

The lab-scale demonstrator includes an energy storage system connected to four solar panels with SmartSolar MPPT 150/35, an EA-PSI 9080-510 programmable power supply and EA-EL 9080-600 programmable electronic load. The energy store comprises of two 12 V 100 Ah lead acid batteries connected in series, where the aim is to monitor the flow of energy between the load, renewable generation and the battery rather than sizing the system. A data acquisition system collects data connected to voltage and current sensors used for system monitoring and data collection at a rate of 1 Hz.

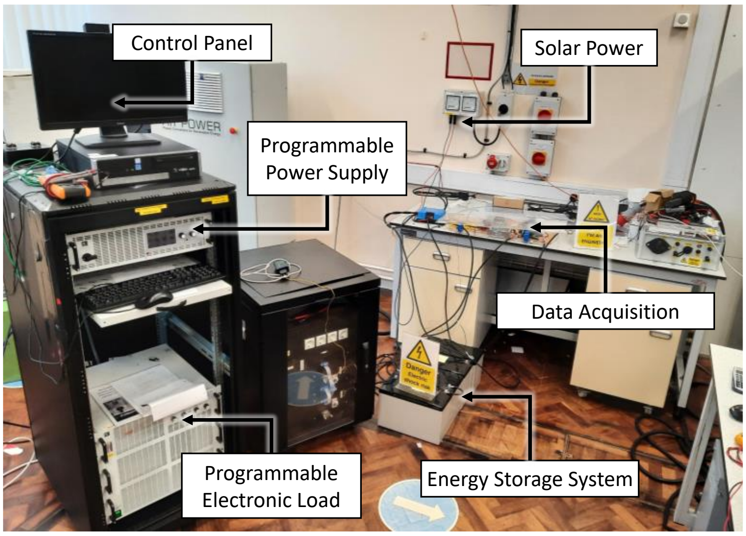

Figure 2: The FEVER lab-scale demonstrator.

The half hourly EV load is determined by assuming a FEVER charging station with ten 7 kW chargers located at a visitor attraction site in the southeast of England. The model uses the daily number of visitors and a visitor arrival profile for a typical year during the site's opening hours from 10 am to 5 pm, assuming four visitors per car, 3% of the vehicles arriving are EVs that typically park for 4 hours, have an efficiency of 4 miles/kWh and require a charge to cover 30 miles. An example day of a simulated EV charging load profile is shown in Fig. 3.

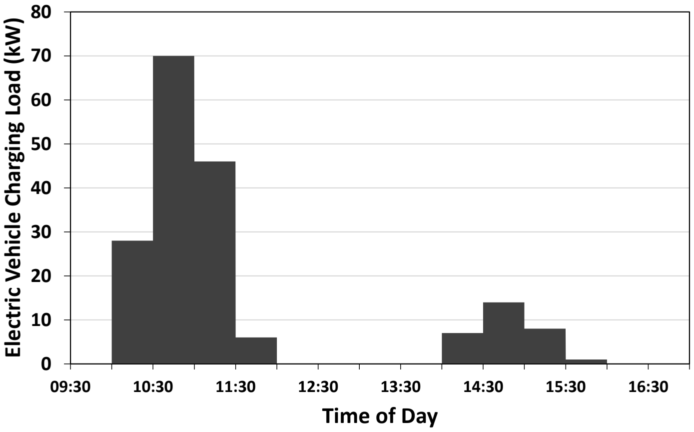

Figure 3: EV charging load profile example day.

Renewables generation at the visitor attraction site was determined using the method given by Naderi et al. [8] using wind speed and solar data from Photovoltaic Geographical Information System (PVGIS) [9] and the power curve of an Aventa AV-7 wind turbine [10]. Additionally, the Photovoltaic (PV) panels on the roof of the laboratory building can directly provide solar generation.

For setting up the experiment, the electronic load provides an EV charging load at 1/100th scale of a modelled charging station at the specified location. An electronically controlled power supply represents renewables generation at a 1/100th scale by combining wind and solar data or wind power if the PV panels are used during the experiment. The battery SOC was calculated using the current sensor data, which was determined using the following equation:

$$SOC_i = SOC_{i-1} + \frac{1}{3600} \cdot \frac{I_i \cdot \Delta t}{C_{batt}} \tag{1}$$

where SOC_i (%) is the battery SOC at time step i, SOC_{i-1} (%) is the previous battery SOC, I_i (A) is the battery measured current at each time step, C_{batt} (Ah) is battery capacity and Δt is the time step interval (s).

3 Results and Discussion

Fig. 4 shows the data obtained from 10 am until 5 pm of an experiment with 1/100 scale EV load and wind power, while the PV panels provide solar power to highlight the behaviour of the battery and renewables generation during the EV charging periods. The battery provided energy mainly during the first period of EV charging load from opening at 10:00 am until 11:30 am, as indicated by the positive battery current values in Fig. 4A. Following the end of the first charging period at 12 pm, where EVs remain connected, charged but drivers are still within the visitor attraction, the solar and wind generation start to recharge the battery nearly full charge just before the second EV load period at 2:00 pm as shown in Fig. 4B. Renewables are sufficient to meet the load demand and recharge the battery during that day, even during periods of low solar generation, as shown in Fig. 4C and Fig. 4D.

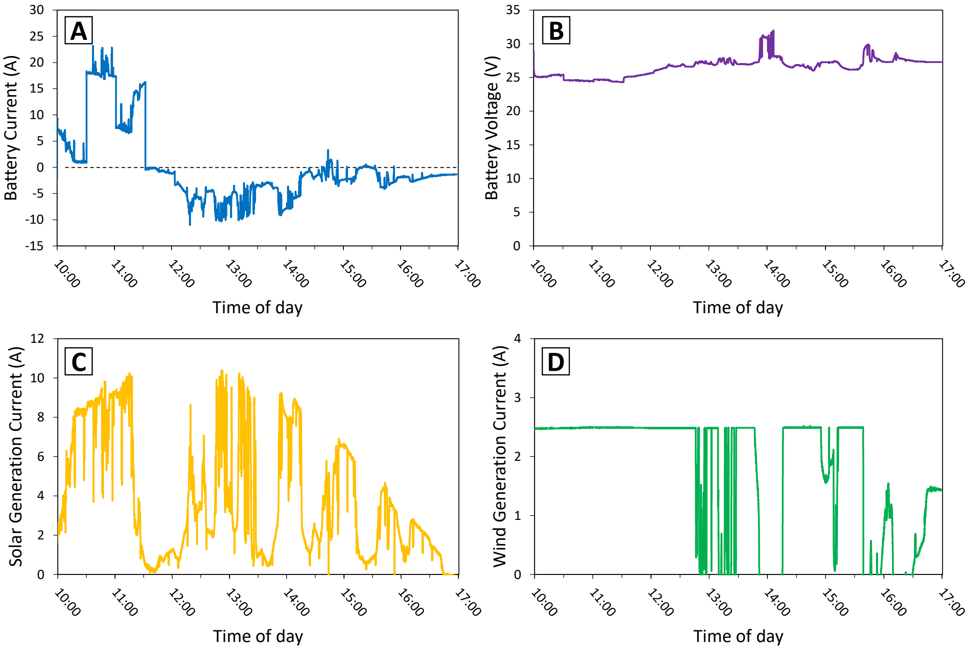

Figure 4: The experiment logged data A) Battery current, B) Battery voltage, C) Solar generation current and D) Wind generation current.

Fig. 5A shows the system's power flow as a stacked plot, highlighting each component's contribution to meeting the load demand shown in Fig. 3 or charging the battery. During the first half hour, the battery had the highest portion of providing power but decreased once solar generation started to increase. When the load demand increased between 10:30 am and 11:00 am, the battery contribution rose and stayed constant as solar and wind generation remained unchanged but dropped again for a short period after 11:00 am as the load decreased. When solar generation started to drop around 11:15 am, the battery provided the needed energy until 11:30 am, where wind generation alone met the load demand. Renewables kept charging the battery until the end of the day, as previously indicated. The impact of this behaviour on the battery SOC is shown in Fig. 5B, where the system battery started from nearly fully charged, dropping to 82.5% SOC midday, and charged again to 100% SOC by 5:00 pm.

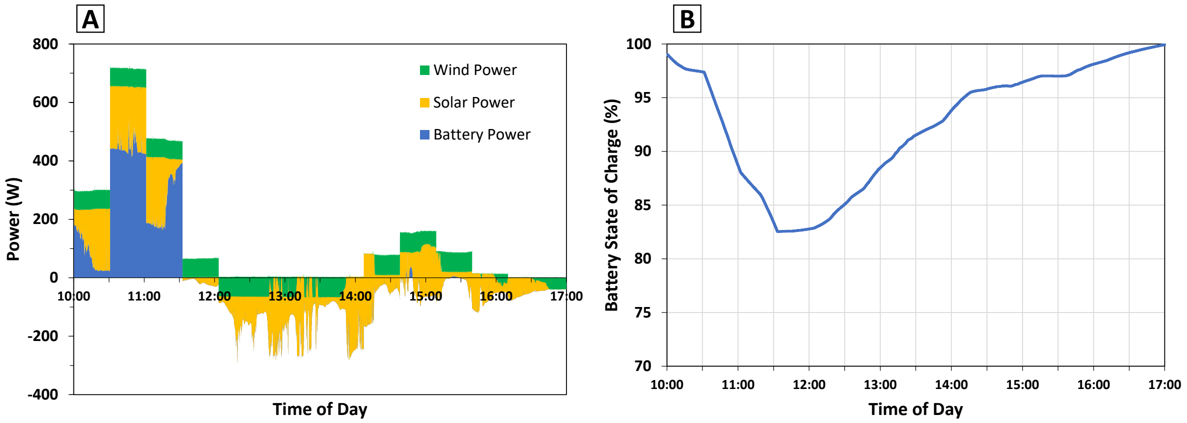

Figure 5: A) Stacked plot showing system power flow. Negative values indicate the power flows to the battery and positive values are for when power is used to meet the load demand. B) Estimated battery state of charge during the day.

While the previous results provide insight into the behaviour of the battery and renewables generation for one day, the EV charging station will operate under different charging loads and weather conditions throughout the year. The duration of running the lab demonstrator experiment at the same timestep makes it unfeasible to capture the system behaviour for an extended period. Scaling the experiment timestep from 30 minutes to 5 seconds enables testing a one year of EV charging station data in one day, which will allow monitoring the changes in performance under multiple scenarios to correctly size the system component and determine the operating conditions of the energy and battery management systems once implemented. The size-scaled and time-compressed experimental analysis method is used in a hardware-in-loop system and battery model validation to overcome physical and time constraints [11].

An experiment has been set up to run for around 24 hrs with a scaled timestep of 5 seconds to represent a one year of operation at the EV charging station. The electronic load delivered the 1/100th scale EV charging load (power), and the power supply provided the combined wind and solar generation at 1/100th scale. The initial battery SOC was around 60%, with a voltage limit set by the power supply to protect the battery from overcharging. Fig. 6A and Fig. 6B show the scaled EV load and power supply currents, respectively, as recorded by the data acquisition for the entire 24-hour experiment duration, simulating a scaled one-year operation.

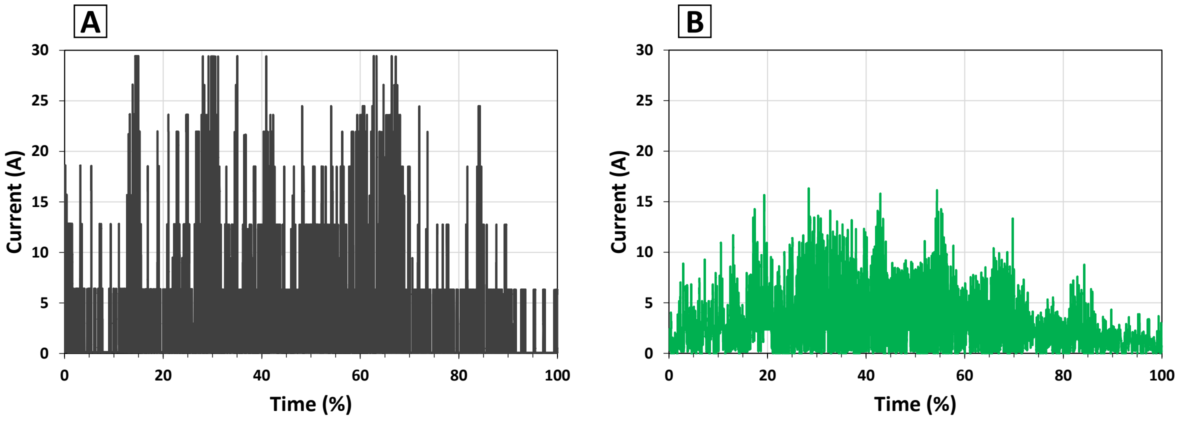

Figure 6: A 24-hour experiment of scaled one-year operation of charging station A) EV load current and B) Power supply current combining wind and solar data.

Fig. 7 shows the battery current during the 24-hour experiment. Discharging current presents the battery contribution to meeting the demand where renewable generation was insufficient to cover the EV load. The charging current presents the excess energy that renewables generate, which goes to the battery. Compare Fig. 7 and Fig. 6, which show that the high current load demand is mainly contributed by the battery, which continues throughout the year.

The behaviour in Fig. 5 and Fig. 7 suggests that a hybrid battery system that combines lithium-ion and lead-acid batteries might suit this application. The hybrid energy storage system (HESS) takes advantage of the differences in both battery characteristics, where the lithium-ion battery covers most of the frequent charge and discharging cycle through the year, while the lead acid battery will operate to assist during high current demand [12]. This HESS will have a lithium-ion battery with a smaller capacity combined with a lower-price lead acid battery, leading to lower overall system cost.

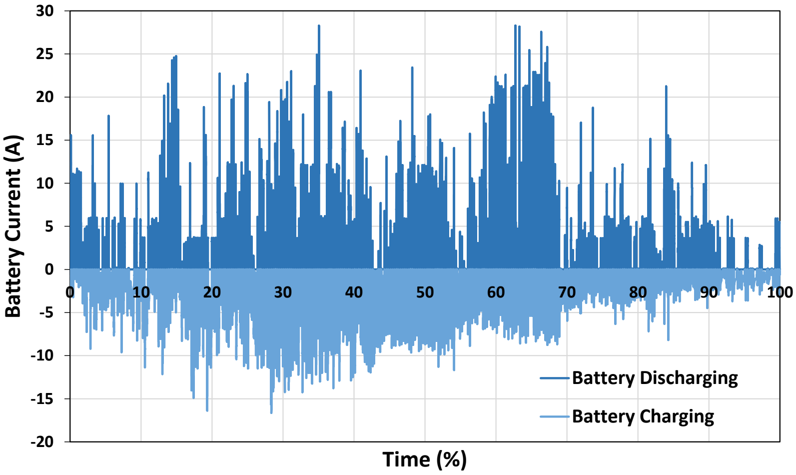

Figure 7: The battery discharging and charging current during the experiment.

Fig. 8 shows the continuous increase in the battery-estimated SOC, starting from 60% and reaching above 95% at the end of the experiment due to the excess generation of renewables. This result shows that installing fewer renewable generation would be sufficient to meet the EV charging load. However, overgeneration can lead to a lower overall cost, by allowing for a reduced battery capacity without affecting the system's sufficiency to cover the demand [13, 14].

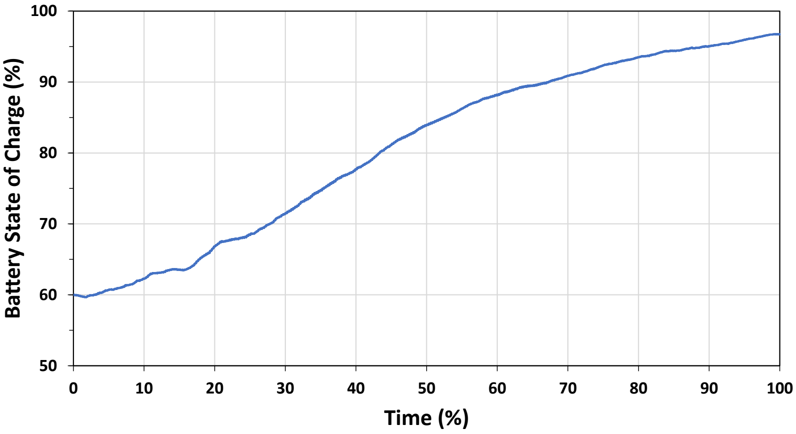

Figure 8: Estimated battery state of charge during the experiment.

As scaling power and time has a compounding effect on the required capacity of the battery. the system could be further developed by implementing an energy management system that artificially limits the energy into/out of the battery in order to limit the capacity of the physical battery to the scale of 1/360.

4 Conclusion

Demonstrators are being developed to represent an off-grid electric vehicle charging station powered by renewable energy coupled to a battery energy storage system. This work presents the lab-scale demonstrator setup, the approach to implement wind and solar generation, and modelling procedures to predict the EV charging load. A test was carried out to present a day of EV charging station operation with 1/100th scaled EV load and renewable generation. The work was extended through a time accelerated method to cover running an entire year of charging station operation by the lab-scale demonstrator in one day to analyse the behaviour of the battery and renewables generation during the period. The results demonstrate the ability of the system to meet the EV charging load demand during the day, and keeping the battery fully charged by the end of the day will ensure sufficient energy is available for the following day. The compressed time experiment shows that lower system cost can be achieved with smaller renewables generation without impacting the charging station's ability to meet the EV load. The system presented is a physical model of a full scale EV charging station. Used in conjunction with computational modelling, future work will allow increased confidence in the performance and relative sizing of components of the full scale system. Further developments could look at testing a hybrid energy storage system and implementing energy management.

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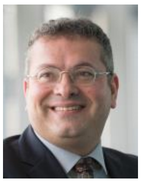
Presenter Biography

Yazan Al-Wreikat joined the Future Electric Vehicle Energy networks supporting Renewables (FEVER) project as a Research Fellow within the Department of Mechanical Engineering at the University of Southampton. Yazan received his PhD in engineering from Aston University. His research interests include electric vehicles, charging stations, EV energy consumption and energy storage systems.



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