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Design of a Portable and Renewable EV Battery Charging System (PREVBCS)

Michael Riggi, Amir Abrari, Nancy Reyes, and Jojo Taylor

Volgenau School of Engineering
George Mason University
Fairfax, Virginia 22030

Corresponding author's Email: Mriggi@gmu.edu

Abstract: One segment of EV owners are people that live in rural areas. Customer interviews of rural EV owners identified the following challenges: (1) power outages that prevent charging at home, (2) limited availability of rapid charging stations in rural areas, (3) highway congestion and extreme weather conditions that can result in running out of battery power, (4) costs of charging, and (5) CO2 emissions from power grid generators that rely on fossil fuels. These challenges identified the need for a portable and renewable method for on demand charging of EVs.

This paper describes the design of a Portable & Renewable Electric Vehicle Backup Charging System (PREVBCS). The PREVBCS is a set of solar panels and an integrated external battery mounted on the EV roof rack. The 100 kg, 0.29 meters^3 unit produces a minimum of 5 kWh when charging in direct sunlight for 8 hours.

Keywords: Electric Vehicles, Solar, Emissions, Renewable, Charging

1. Context Analysis

There are 290.8 million cars registered in the United States as of 2022. In 2023, EVs make up 5.8% of new cars sold in the US (Nedelea, 2023). One segment of EV owners are people that live in rural areas. An estimated 400,000 are EV owners that live in rural areas. This growth is the result of competitive pricing and quality in the EVs compared to traditional internal combustion engine vehicles. EVs are climate-friendly by not directly emitting GHGs; typically producing 1/3 of the C02 that a gasoline car produces (Department of Energy, 2021).

Over 30 stakeholder interviews of rural EV owners identified 5 challenges:

1. Power grid outage due to weather and/or rolling blackouts prevent charging EVs at home.
2. EV can run out of battery from extreme temperatures and/or congestion and prevent operators completing a trip.
3. Inoperable public charging stations prevent operators from charging.
4. EV charging pays the going rate for electricity in the area which can be expensive.
5. CO2 emissions from charging when the power grid uses electricity generated from fossil fuels.

It is not uncommon in States like California for the state's electric grid operator to issue an "Energy Emergency Alert 3" requesting residents maximize conservation and expect rotating outages as the grid strain is 'going to get intense' (Catenacci, 2023). This presents a major challenge to EV owners when needing to charge their EVs.

EVs can run out of battery from Extreme Temperatures and or severe traffic congestion. Temperatures less than 20 °F cut EV range by 41% and temperatures greater than 95°F decrease range by 17% (AAA, 2019). As climate change intensifies and extreme temperatures (both hot and cold) become more prevalent across the US, EV owners may experience reduced range due to the performance of the batteries on trips where the EV owner may experience traffic congestion.

A 2022 JD Power survey found that 21% of the time EV owners found that the closest charger to them was inoperable (Tucker, 2023). For rural EV owners, where EV chargers are sparce this presents a serious limitation in the ability to charge when needed.

Charging is not inexpensive. Charging station rates range from \$0.20 to \$0.60 per kWh, which equates to \$10 to \$30 per charge, or \$1,560 per year assuming \$30 of charging per week (Sharbono, 2023).

The final issue is CO2 Emission of Charging EVs. According to the Energy Information Administration, on a given day in America only 22% of electricity production is generated using renewables. Most of America is reliant on coal and other non-renewables to power the electric grid (EIA, 2023). In this way, EVs do not directly emit GHGs but in the process of charging, the electricity used is largely generated from fossil fuels.

AS-IS processes were developed for each of these issues. Figure 1 illustrates the situation when an EV runs of charge due to extreme temperatures or traffic congestion. The red boxes in the AS-IS Process below are the current performance gaps relating to how EVs run of charge before reaching their intended destination.

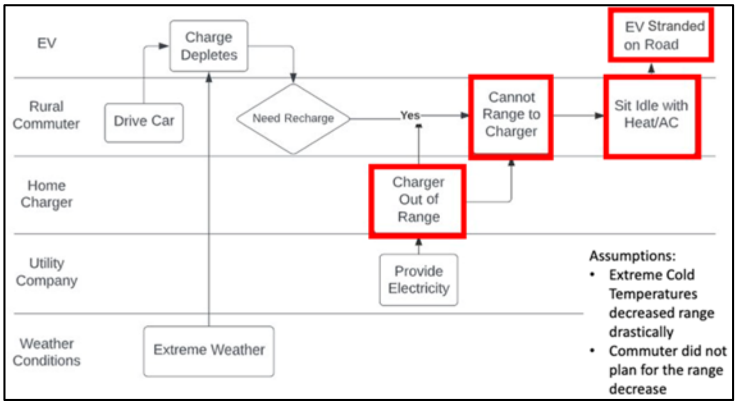

Figure 1. EV Running Out of Charge AS-IS Process

2. Concept of Operations

The concept of operations is to include a portable and renewable system that can charge an EV battery using solar power. The solar charging system can be deployed to charge the EV battery when the power grid is not available. The portable charging system can also be deployed when the EV runs low in traffic congestion compounded by hot/cold temperatures or when public charging stations are inoperable. The solar panels can charge the EV battery without having to bear the costs of the power grid. The solar panels also charge the EV battery without generating CO2 emissions from a fossil-fuel dominant power grid. This system is named the Portable Renewable EV Battery Charging System (PREVBCS).

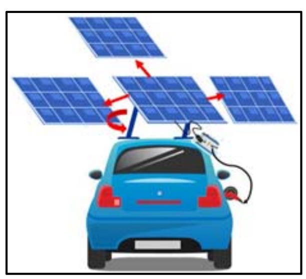

Figure 2. Concept of Operations

3. Requirements

18 Mission Requirements were developed for a the PREVBCS. To adhere to the page limit, only the first 2 mission requirements listed below:

MR 1: The PREVBCS shall Produce at least 5 kWh per 8 hours of direct sunlight charging.

This requirement is derived from the following logic. The average round trip daily commute for rural residents is 41 miles (Flynn, 2023). Assuming 4 miles per kWh of charge, the PREVBCS would be able to extend the EV's range by about 20 miles, or enough to return from work after an 8-hour workday while the system is charging in direct sunlight (Kurczewski, 2023).

MR.2: The PREVBCS shall add less than 20% drag force to the existing car at 100 MPH.

A main goal of PREVBCS is to extend EV range by providing extra charging capabilities, but not at the expense of reduced range. The extra drag incurred by having PREVBCS installed should not decrease the EV's range more than PREVBCS can add.

To investigate this, a CAD model of PREVBCS installed on a Tesla Model S was designed in Solid works fluid flow simulation software (Figure 3). The CAD model specifically leaves space between the solar panels to allow air to pass through them and minimize the added drag, resulting in an added frontal area of only 0.13 meters squared. Tests were performed at 10 MPH increments from 0 to 100 miles per hour to calcite the added drag force of the system. At all velocities, added drag was less than 13%. According to road tests done by Car and Driver, for every 10% increase in drag, range decreases by 5%. Using the data, the 13% added drag of PREVBCS would decrease an EV's range by about 6.5% in a worst-case scenario of exclusively high-speed highway driving, but in lower speed cases decreases far less, thus maintaining PREVBCS' utility.

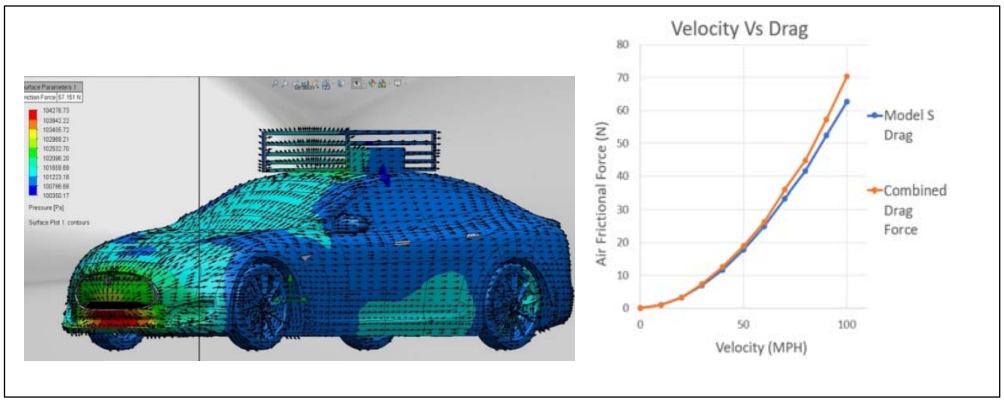

Figure 3. PREVBCS Drag Simulation and Velocity vs. Drag Chart

4. Design

The PREVBCS is a set of 5 vertically stacked solar panels and an integrated 5 kWh external battery that can charge an EV on demand (Figure 4). The unit is mounted to the EV roof rack via nuts and bolts and has a set of sliding solar panels that can be extended to charge the battery.

A CAD design of the unit shows that it weighs less than 100 kg and has a volume of 0.29 meters^3 (Figure 4). Up to five solar panels can be deployed via ball bearing slide mounts while the vehicle is parked in the sun to produce a minimum of 5 kWh per 8-hour charging session (Figure 4). The sliding mechanisms allow a minimum footprint while maximizing surface area of deployable solar panels. The allows PREVBCS to convert enough solar radiation into electricity to extend an EV's range up to 20 miles, which is half the average daily round trip commute length in the US, in an 8-hour charging session.

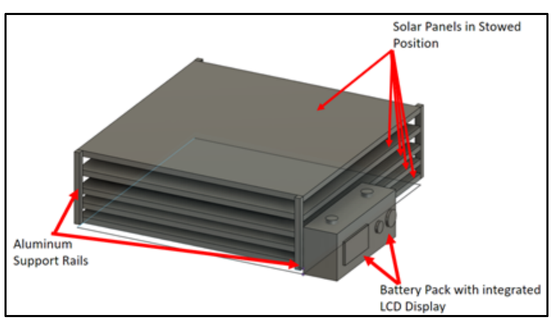

Figure 4. CAD Design

The main components of the portable renewable system are:

1. Roof Rack Mounting
2. Extensible Solar Panels
3. Solar Panels
4. External Battery

The system's extending capability will be facilitated by a sliding system consisting of channel members and slide members as shown in figure 5.

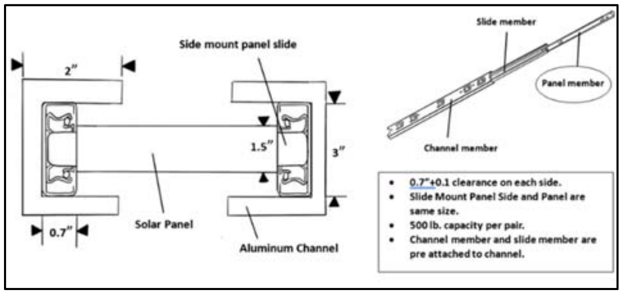

Figure 5. Sliding System Design

When fully deployed, PREVBCS will have a total of 4 panels that slide horizontally to each side of the vehicle, as well as 1 top panel that stays in place, resulting in 5 deployed panels and allowing up to 5 square meters of solar panels to be charging the EV at a time. This concept is illustrated below in figure 6.

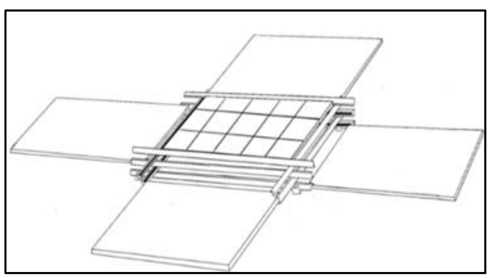

Figure 6. Extended PREVBCS design

4.1 Design of Solar Panels

A Multi-Attribute Utility analysis was conducted for the selection of the solar panels. The following attributes were derived from the mission requirements: dimensions, efficiency, weight, and power output. Weights for each attributed were developed using a pair-wise method as follows: Power output had the highest weight of importance (0.33), followed by efficiency at (0.30), Weight at (0.23), Dimensions (0.13). The weights show how significant each scoring value was to the overall score of the utility functions. Values for each attribute were assigned based on the manufacturer specifications for the following solar panels: HQST 100-Watt Monocrystalline Solar Panel, RICH SOLAR 200-Watt 12 Volt Solar Panel, Canadian Solar 290W Solar Panel, Grape Solar 370-Watt Solar Panel.

The preferred solar panel is the RICH SOLAR 200-Watt 12 Volt Solar Panel as it had a good power output, high tier efficiency, good weight, and close to acceptable dimensions, requiring slight modification to design. Based on the scoring of each product in the table, the selected solar panel stood out when analyzing each score against the weights designated. The calculation for kWh production using the selected panel is as follows: 5 panels x 8 hours x 200 watts x 0.75(efficiency loss) =

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6000 daily watt-hours (Solar Kits, 2022). Moving forward with production, RICH Solar will be contacted, and 1 square meter solar panels will be requested via their wholesale program to fit PREVBCS' design.

4.2 Design of External Battery

A Multi-Attribute Utility analysis was conducted for the selection of the external battery pack. The following attributes were derived from the mission requirements: Nominal capacity (Ah), nominal voltage (V), weight, kWh production, and dimensions. Weights for each attributed were developed using a pair-wise method as follows: kWh production had the highest importance (0.30), followed by weight (0.24), dimension at (0.22), nominal capacity (0.15), and nominal capacity (0.09). The weights show how significant each scoring value was to the overall score of the utility functions. Values for each attributed were assigned based on the manufacturer specifications for the following external battery packs: Junlee 100Ah 48V, Junlee 200Ah 48V, LiFePO4 400Ah 12V, LiFePO4 200Ah 48V.

The preferred battery pack is the Junlee 200Ah 48V External Battery Pack as it had the target kWh production from the requirements, good weight, proper dimensions, and acceptable nominal capacity and voltages. Based on the scoring of each product in the table, the selected battery pack stood out when analyzing each score against the weights designated. The results of the MUAT are summarized in Figure 7.

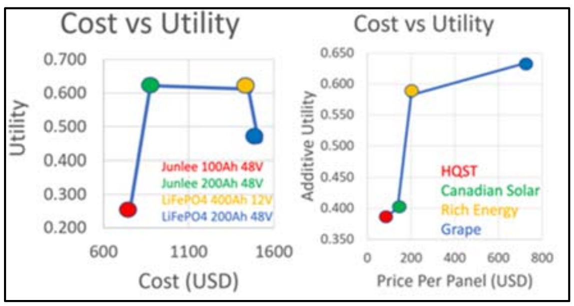

Figure 7. Multi-Attribute Utility Analysis Graph. Left: Solar Panel, Right: Battery pack

4.3 Installation Usability Testing

An installation and a user manual were developed. A Monte Carlo simulation model of the installation of the roof rack was conducted in the Sopatra Tool (Dam, 2023). The mean installation time is 33.75 minutes. An estimated 5.3% of the installation required more than the target threshold time of 37 minutes.

5. Business Plan

The PREVBCS is a portable, renewable charging system for EVs. The PREVBCS is mounted on the roof of a car. The solar panels can be extended to charge the car when the car is parked.

The PREVBCS product has 5 primary value propositions within the market:

1. Power Grid Outage due to weather and/or rolling blackouts prevent charging EVs at home.
2. EV can Run Out of Battery from Extreme Temperatures and/or congestion and prevent operators completing a trip.
3. Inoperable public Charging Stations prevent operators from charging.
4. EV Charging pays the going rate for electricity in the area which can be expensive.
5. CO_2 Emissions from Charging when the power grid uses electricity generated from fossil fuels.

The total market segment of the PREVBCS product accounts for 400,000 potential rural EV owners. The rural population accounts for 20% of the US population while there are currently 2 million EV and Plug-In Hybrid owners in the United States. The two factors combined produce 400,000 potential customers.

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