Comparative Analysis of Energy Cost for Different Configurations of an EV Charging Station in the Jamaican Context

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Abstract - With the 2021 roll out of the ten electrical vehicle (EV) charging stations across Jamaica, there is now a need to provide alternative energy sources in keeping with the government's mandate to have 50% renewables by 2030. This research focused on the viability of switching from grid power to solar photovoltaic for the charging of EVs. Subsequently, it entailed the design and costing of a photovoltaic standard EV charging station with battery storage. A comparative analysis of four configurations were explored in order to determine the most feasible arrangements. These configurations were a grief powered EV charging station, a grid-tied configuration, a hybrid configuration and a stand-alone configuration. Analysis using Homer Pro software determined that a grid-tied configuration would be most economically feasible at US 10 cents per kWh while a standalone configuration would result in the least carbon emissions with zero emissions over the lifecycle operation of this configuration.

Keywords: electric vehicles, solar energy, solar photovoltaic, electric vehicle charging station

I. INTRODUCTION

Jamaica's National Energy policy has recognized the need to reduce the dependence on imported fuel as a major priority for the island's energy security. This is further corroborated when in 2017 81.3% of the total primary energy supply was derived from oil [1]. The Jamaican transport sector accounted for 37.3% of the total energy consumed in 2017 and further highlights the potential benefits of having the infrastructure to facilitate EVs [1]. Stemming from this, it is imperative that the island fosters the development of renewable energy technologies that would bolster the electric mobility sector. The main purpose is therefore to design EV charging stations, which have renewable energy as the power source.

A. Jamaica's EV Status

Currently, it is estimated that there are twelve (12) full electric vehicles in Jamaica [1]. Coupled with this fact, in 2016 514,316 vehicles were registered on the island. As a result, this positions the island as the Caribbean's largest potential EV market. The Government of Jamaica (GOJ) has commenced the development of the Electric Vehicle Policy and a regulatory framework [2]. Additionally, the Inter-American Development Bank (IDB) is assisting the GOJ in the development of the strategic framework for electric mobility. This framework would not only inform policy but will foster a seamless transition to battery electric vehicles (BEVs) [3]. In order to meet the potential demand for EVs, the local power company, The Jamaica Public Service (JPS), has already rolled out the completion of 10 EV charging stations across the island in the first quarter of 2021. Each being an estimated 40 km apart [4]. The addition of larger loads to the grid such as electric vehicle charging stations (EVCSs) would consequently require efficient grid operation.

The fact that EVs are about 50% more efficient in converting liquid fuels to motive power, even when powered by electricity generated from oil derivatives is phenomenal and a key driver in their integration in the Jamaican society [3]. Moreover, it costs about 50% less to drive the same distance as an internal combustion engine vehicle (ICEV), even with the existing fuel mix and the high electricity rates of US$ 0.40 in Jamaica [3].

B. Energy Storage Technologies

The main purpose of an EVCS is to transfer electricity to an electric vehicle so that the batteries can be recharged safely and efficiently [5] (Rouse, 2018). Currently, there are two primary energy storage technologies used for RET, namely, lead-acid and lithium-Ion. Lead-acid batteries are the primary energy source technology for off-grid systems. Deep cycle lead-acid batteries are the most widely used and studied and are known to have challenges such as a

high depth of discharge of 50% and a relatively short operating life of 500 to 1000 cycles [6].
There has been an increase in both the demand and supply ability of lithium-ion batteries, for example, Tesla made a leap and installed a 129 MWh lithium-ion bank in Australia [7]. Lithium-ion batteries have the highest charging efficiency, high energy density, and low self-discharge characteristics [8]. In other words, they can efficiently charge and discharge for about 2000 to 5000 cycles with a depth of discharge (DOD) of 80% [8]. Moreover, these properties make them primarily suitable for electric vehicles and off-grid systems. However, a major limitation is that they are more expensive and have safety challenges.

C. Grid Powered Charging Stations

A single electric car constitutes a load of 11 to 50kW. Consequently, the grid load and stability need to be considered when stations are being developed due to the fact that several vehicles connected simultaneously at a charging station can cause a significant charging impact on the grid.

There are three levels of charging stations. Level 1 refers to the electricity provided by a standard 110V AC wall outlet and with this low-level outlet, 4-5 miles per hour is delivered [9]. Level 2 is the standard for daily charging and uses a 208/240V AC setup. Having double the voltage of a 110 V outlet, a 30A charging station can charge electric cars at 25 miles per hour. Level 3 DC Fast Charging stations use 200-600V DC and 50+ kW and most are able to charge EVs in less than one hour [9 . In addition to this, both level 1 and 2 charging are standardized, however, EVs can have one of three connections for charging stations, namely CCS, CHAdeMO, or Tesla. As a result, drivers need to be aware of their vehicle plug type to access a charging station [9]. The Jamaica Public Service will be installing seven Level 2 charging stations and three Level 3 Charging stations in 2021.

D. Solar PV Charging Stations

The rate of charging of EV batteries is constrained by the solar photovoltaic panels' ability to generate electricity. As it relates to EV, the challenge is that as the industry and acceptance of EVs increase, there will be a demand for power which has the potential to aggravate the grid load [10]. This leads to an exploration for alternative and clean sources of energy to charge EVs such as solar photovoltaic[10].
The charging of an electric vehicle from solar power in an unshaded area will require a PV system ranging from 2 kW - 14 kW [11]. The installation of a solar canopy in a parking lot would offer not only car covering but the provision of clean electricity [12].

II. MATERIAL AND METHODS

The methodology was chosen to provide an overview of the relevance of EV charging stations in the Jamaican context, analyze the effects of ambient conditions on possible designs, and investigate the cost-effectiveness of implementing such a solution. This section of the paper will discuss the design process of an EV charging station that can be employed in tropical conditions. It will also explore the methods utilized to develop simulation models to test the proposed design and analyze the data from the models in order to determine the suitability of the results.

A. Design of the EV

The engineering design process was selected as the method used to develop the design of the EV charging station [13]. This process allowed for iterations in order to make modifications to initial designs.

The specific design requirements for the EVCS is shown in table 1 below. The lithium-ion battery was only required for the standalone and hybrid configurations and was chosen for the depth of discharge as well as energy density compared to lead acid which is a cheaper alternative. The selected design was then developed and the model then tested to ensure that the design specifications outlined in table 1 are met. Since the process was iterative, the results were then communicated and modifications carried out once requirements such as peak power and system efficiency were not achieved. Consequently, it was accepted if all the aforementioned requirements were achieved. Further modifications were made if the requirements were not met, while the product is accepted if all requirements are met.

E Functionality Testing

It is necessary to assess the functionality of the design to ensure that minimum functional requirements such as capacity, peak power, system efficiency and charging voltage, as outlined in table 1 below, are met. Functionality testing of the design was done using simulations from Autodesk Inventor and MATLab Simulink. Autodesk Inventor was used to create the engineering drawing, 3D model and to conduct structural analysis on the selected design using finite element methods. MATLab Simulink was then utilized to conduct a performance analysis on the system using the proposed system size in order to ensure power requirements are met under a range of local environmental conditions.

Table 1 showing Specific Requirements of EV charging station

Description	**Value**
Lithium-ion battery depth of discharge (DOD)	<=80 %
The average distance travel per day (d)	25 miles/ 40 km
Number of cars charged per day (n)	4
Peak watt of the panel used (P_{pan})	240 Wp
System Efficiency (η)	80%
Nominal voltage of each 18650 cell (Vnc)	3.7 V
Capacity of each 18650 cell (C_{cell})	2600 mAh
Average full sun hours (Full sun)	6 h
Nominal voltage of the battery pack (V_{nomsys})	48 V
Nominal voltage of each panel (Vnp)	24 V
The total energy required (T_E)	60 kWh

B. *Feasibility Testing*

The economic feasibility of four proposed configurations for the ECVS was conducted in order to determine the most optimal design. These are a grid-powered configuration, a grid-tied PV configuration as shown in figure 1, A hybrid system and a standalone PV system as shown in figure 2. Homer Energy Software was used to model the system under similar load profile and environmental conditions for all four configurations and to simulate both the cost and carbon emissions associated with each. The grid-tied configuration uses the grid as energy storage as shown in figure 1, while the hybrid configuration utilizes both the grid and lithium-ion batteries as backup-storage. On the other hand, as seen in figure 2, the standalone system shares no connection with the grid, while the grid powered configuration does not require solar panels or batteries. A comparative analysis of all four configurations was then conducted to identify the most feasible setup. The main features of the comparative analysis included utilizing Homer Pro to model the parameters of each configuration, including the load profile, peak power, inflation and interest rates, capital and operating costs and carbon emissions from operations.

Figure 1 showing schematic of Grid-Tied PV Configuration

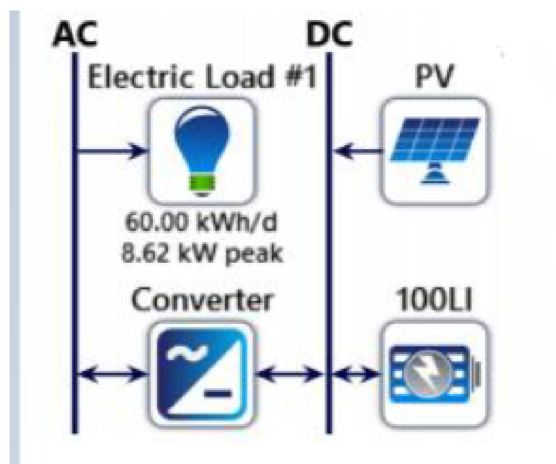

Figure 2 showing schematic of PV Standalone configuration

III. RESULTS AND DISCUSSION

A. *Final EVCS Design*

The EV station was designed to meet the requirements outlined in table 1. Figure 3 below presents a 3D render of the final design while table 2 presents a list of the major parts. Figure 4 also provides an engineering drawing which highlight the major dimensions of the housing.

Aerospace grade aluminium 6061 was chosen as the housing for several reasons. Firstly, its high strength-to-weight ratio makes it able to withstand strong winds and lateral loads without significant deflection. This is confirmed by the results of the Finite Element Analysis (FEA) shown in figure 5. Additionally, this material is resistant to corrosion in outdoor conditions and its thermal properties enable quick dissipation of heat from the housing when the battery pack heats up.

Lithium ion batteries, although more expensive than lead-acid, were chosen for the battery pack. It was deemed more suitable due to its high energy density as well as its superior depth of discharge and number of charge cycles available.

A J1772 SAE standard connector (5 pin) was selected for its fast charging characteristics and added safety as well as its ability to determine if a vehicle requires more current than the station can provide and prevent the vehicle from discharging.

Figure 3 showing 3D render of EV charging station

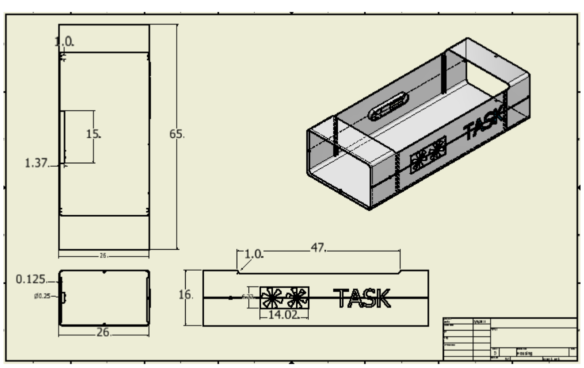

Figure 6 showing engineering drawing of charging station housing

Table 2 showing list of major components in the design of the EVCS

Base	Head	Locking Ball
Base Gasket	Head Seal	Station Damper
Base Plate	Cord Holder Gasket	Damper
Base Seal	Cord Holder	Connector
Head Nut	Head Harness	Connector Holder Gasket
Battery Frame Holder	Head Harness Seal	Connector Holder bolt
Battery Frame	Ground	Cord Seal
Base Bolt	Master Bolt	Cord Locking Nut
Housing	Roller	Cord Nut
Base Washer	Roller Pin	Light Cover
Door	Door Gasket	Battery Cover

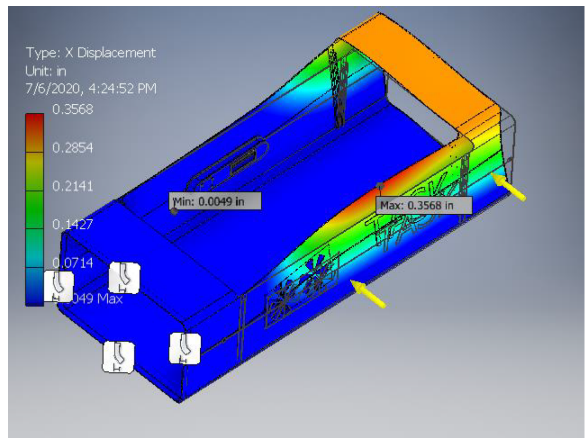

Figure 5 showing results of Structural Analysis using FEA on the charging station housing

B. Economic Feasibility

Analysis of the economic feasibility was conducted and the results are summarized in Table 3 below.

With reference to Table 3, the analysis revealed a standalone system to be the most costly to and it was also the most environmentally friendly with no carbon emissions. The high cost is attributed to high capital costs associated with purchasing and installing PV array as well as the lithium battery back. The operating cost is also that high due to the need to replace battery packs during the system lifecycle. However, it is the cheapest to operate once initial investments have been made as only periodic maintenance of system would be required until battery change is needed, approximately every 5-8 years. Conversely, in remote areas it could be cheaper to implement standalone systems than to run power lines and this is an additional benefit.

A grid-powered system appears to be the most economically viable to implement as there are no capital costs. Due to existing infrastructure, the operating cost will be dependent on oil prices as well as the markup associated with the power service company which can cause it to be costly and volatile.

Currently, the cost of electricity locally is forty US cents per kilowatt-hour and that is expected to increase with rising global oil prices and a rapidly devaluing local currency. Additionally, EV charging has the possibility to affect the load demand on the grid in an unpredictable way. Consequently, this would require financial investments focused on increasing grid capacity in order to meet the increased demand resulting from multiple vehicles charging simultaneously.

The carbon emissions associated with configurations involving connection to the grid totals over 13,000 kg per year. This is due to the fact that once the power grid is being used to subsidize the power being utilized by the charging station, the source of the grid energy generation would be considered. Comparatively, it can be seen that a grid powered configuration would generate just about 11kg more carbon emission annually than a grid-tied system but almost 500kg more than a hybrid configuration. Conversely, a standalone system would not generate any significantly measurable quantity of carbon emissions.

A hybrid system is also costly compared to grid-powered and grid-tied but less costly than standalone. The high start-up cost results from capital investments in both purchasing battery and additional equipment required for grid-tied operations. The benefits of this system would be a 4% reduction in carbon emissions as well as a more robust and reliable system in meeting unpredictable load demands. It has a comparable cost of electricity to current local electricity rates at 43 US cents per kWh. This configuration would pull from battery stores when the power being generated by PV arrays is not enough to meet demand. Excess power would be stored to the grid when battery banks are full. This configuration also provides additional reliability, as there are two back-up sources for the charging station and excess power can also assist in meeting grid demand.

Finally, it is seen from Table 3 that a grid-tied configuration is the most feasible arrangement. This is as a result of the grid being used as energy storage, eliminating the need for batteries and hence the capital costs associated with sourcing batteries. As such, additional energy can be stored on the grid during excess energy generation from PV panels and can be withdrawn from the grid when demand is higher than the PV panel production. This reduces the capital costs associated with standalone systems as well as the operating costs associated with grid-connected systems. This would bring into effect net-billing provisions available locally which would facilitate the sale of excess power to the power service provider at a specified rate and purchase of power from the said power service provider at an agreed rate.

Table 3 showing levelized energy cost for each configuration

Configuration	Capital Cost (USD)	Operating Cost (USD)	Net Present Cost(USD)	Carbon Emissions (kg/yr)	Levelized cost of Energy (USD)
Grid Powered	-	-	-	13842	0.43
Grid-Tied	203.65	21,376	21, 566	13831	0.10
Hybrid	72,394	30,598	102,745	13379	0.43
Standalone	260,080	31,184	286,327	0	0.70

IV. CONCLUSION

From the data presented and discussed a robust design for a EVCS was created, which is structurally capable of withstanding tropical environments while charging four EV per day. The data suggests that a grid-tied configuration would be most economically feasible due to the high costs associated with current battery technology. Conversely, a hybrid system would be most robust and reliable due to redundancies in energy storage. Although a standalone configuration is currently the most expensive to implement due to its high capital costs, it results in the least carbon emission and may be a better solution in remote areas away from electric grids.

Recommendation and Future Work

The following recommendations can be made based on the aforementioned findings and conclusions:

1. Partner with the Jamaica Public Service to conduct joint research.
2. Future work can be carried out to do an analysis to determine the cost for grid integration.
3. Building a prototype in order to conduct performance analysis and compare with simulation data is also recommended to corroborate the research.

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