International Journal of Engineering Innovation & Research
Volume 15, Issue 1, ISSN: 2277 – 5668

Building Wireless Charging Infrastructure for Electric Vehicles: An Analysis of Zambia's eMobility Framework

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Date of publication (dd/mm/yyyy): 28/02/2026

Abstract **– Electric vehicles (EVs) are transforming mobility around the world by providing a sustainable alternative to fossil fuels. Their presence within the global automotive sector is expanding rapidly, supported by international commitments to curtail greenhouse gas (GHG) emissions. The global acceleration of EV adoption suggests that even countries such as Zambia, will soon experience its influence-opening pathways for technological innovation and environmental resilience. Nevertheless, Zambia's transition to EVs is constrained by limitations in its energy infrastructure, a common challenge for emerging markets. This paper explores the Zambian government's policy framework for establishing a charging infrastructure for EVs (CIEV), with particular emphasis on rural deployment along the 584-kilometer corridor connecting Lusaka to Chipata.** **Electric vehicles (EVs) are transforming mobility around the world by providing a sustainable alternative to fossil fuels. Their presence within the global automotive sector is expanding rapidly, supported by international commitments to curtail greenhouse gas (GHG) emissions. The global acceleration of EV adoption suggests that even countries such as Zambia, will soon experience its influence-opening pathways for technological innovation and environmental resilience. Nevertheless, Zambia's transition to EVs is constrained by limitations in its energy infrastructure, a common challenge for emerging markets. This paper explores the Zambian government's policy framework for establishing a charging infrastructure for EVs (CIEV), with particular emphasis on rural deployment along the 584-kilometer corridor connecting Lusaka to Chipata.**

Keywords **– Infrastructure, eMobility, Charging, Wireless, Electric Vehicle, CIEV.**

I. INTRODUCTION

In July 2023, Zambia had just 62 registered electric vehicles and by July 2025, that number had surged to 269 EVs, marking a 330% increase in just two years [1]. While the numbers are still modest, the growth rate signals rising interest and potential for broader adoption. In support of this, the Zambian government has eliminated customs duties on motorcycles, cars and charging equipment. The Excise duty on hybrid vehicles was reduced from 30% to 25%, making cleaner transport options more accessible [1, 2]. These policy reforms are designed to foster a green economy and promote sustainable industrialization [2]. Organizations like the Zambian Electric Mobility Innovation Alliance (ZEMIA) are actively working to build a robust EV ecosystem through incentives and policy advocacy, [3]. ZEMIA has established seven working groups with each initiative carrying a distinct focus and goal, contributing to a holistic, step-by-step strategy for advancing electric mobility [3]. These groups are: (1) Policy, Regulation & Standards; (2) Charging Infrastructure; (3) Research & Development; (4) Techno--logy; (5) Electric Motor Vehicles & Cycles; (6) Battery Storage; (7) Supply Chain and Innovation.

A. *Problem Statement*

Zambia currently lacks public EV charging stations, especially outside major urban centers. This stands to restrict long-distance travel and discourages consumer adoption of mobility using EVs. The country also suffers from an inadequate and aging grid system whereby unmanaged charging loads could destabilize the grid, especially during peak hours.

B. *Research Objectives*

The objectives of this work include: (1) to examine the possible implementation of the Zambian governments e-mobility policy framework; (2) to investigate the relevant technologies necessary in the deployment of class 3 DC fast-charging systems, using solar as the primary source of energy; (3) to promote consumer awareness & confidence. Many potential EV buyers are hesitant to invest in this technology due to uncertainty about where and how to charge their vehicles, especially in rural areas.

II. LITERATURE REVIEW

Discussed compensation topologies to improve power transfer efficiency and provided a broad overview of static and dynamic wireless charging systems [6, 7]. Explored resonant inductive coupling and safety considerations [8]. Reviewed dynamic charging systems and infrastructure integration [9]. Highlights market diversity in battery electric vehicle BEV models and implications for charging infrastructure [10]. Focused on location planning and optimization strategies for wireless charging stations [11] and focused on coil design and magnetic coupling efficiency in IPT systems [12].

A. *E-Mobility Policy Framework*

Zambia's EV policy isn't a single document but a framework emerging from national strategies like the Green Economy and Climate Change Act (2024) [13] and the National Energy Policy (2019), focusing on renewable energy, climate resilience [14], and green jobs, with supporting initiatives like the World Bank's National Energy Compact promoting renewables, off-grid solutions, and private investment in infrastructure, alongside specific regulatory guidelines for EV charging pricing by the Energy Regulation Board (ERB). Green Economy and Climate Change Act, 2024 Aims for a low-carbon, climate-resilient economy, guiding green initiatives. The National Energy Policy (2019) outlines strategies for sustainable energy, including generation, transmission, and supply. National Green Growth Strategy (2024-2030) [15] Promotes low-carbon, inclusive development, supporting green transitions. The e-Mobility policy focuses on the deployment of EVs in a sustainable way [16]. National Energy Compact (World Bank) focuses on expanding generation (renewables), regional integration, clean cooking, and private sector engagement [17]. Energy Efficiency Strategy and Action Plan forms part of Zambia's efforts to develop sustainable energy [18]. The Rural Electrification Act aims to expand electricity access, crucial for EV infrastructure [19]. The Transport and Infrastructure Policy seeks to promote modernization of transport systems, including EV adoption [20]. The eMobility framework is focused around incentivizing EV acceptance and use by promoting EV related courses in universities and colleges to get the younger generation to accept the technology [16]. This also involves EV charging infrastructure roll out in shopping centers and workplaces [16, 20]. The policy also seeks to encourage locally developed and affordable EV solutions with modest ranges for daily use. Principally the policy endeavours to promote the development of EV charging infrastructure [16]. It does this by promoting home and workplace charging and developing guidelines for national charging systems. Zambia being a country with a crippling energy crisis, the policy places emphasis on renewable energy sources (solar, hydro) for future power generation, supporting EV ecosystem [18].

III. METHODOLOGY

This study employs a mixed-methods approach, emphasizing both policy analysis and the technical design of an EV charging system that integrates solar photovoltaic (PV) panels with battery energy storage to deliver sustainable, cost-effective, and reliable charging solutions. EV charging infrastructure is generally categorized into three levels according to power capacity and charging speed [4]. Level 1 relies on a standard household outlet, offering slow charging that may require 22-24 hours for a full charge [5]. Level 2 utilizes a 220V supply, enabling faster charging at residential or public facilities, typically completing a full charge within 3-13 hours [5]. Level 3, or DC Fast Charging, employs high-power direct current to facilitate rapid charging during extended travel, often achieving up to 80% capacity in less than an hour, with typical charging durations ranging from 15 minutes to 1.5 hours [4, 5].

A. *Specifications for Wireless Charging Systems*

To ensure compatibility with modern EVs, Zambia's infrastructure must align with international standards. Standard wireless charging system delivers between 3.7-11 kW which is suitable for domestic application [3, 4, 5]. Fast wireless charging delivers between 50-250 kW which is suitable for commercial applications such as buses, taxis, and fleet vehicles [4, 5]. Technical specifications include: Frequency range of 85 kHz (as per SAE J2954 standard); Efficiency of 90-93% energy transfer efficiency; Alignment tolerance between the coils normally form within ±10 cm lateral, ±7 cm longitudinal [21].

B. *Solar-Powered Wireless Charging Systems*

Zambia's high solar irradiance (5.5 ~ 6.5 kWh/m²/day) makes solar integration highly feasible [22]. The PV Arrays mounted on rooftops or ground-mounted panels at charging stations will be the primary source of energy. The proposed energy storage system utilizes lithium-ion technology to capture and retain surplus solar energy. A hybrid grid configuration is envisioned, whereby solar-powered EV infrastructure is supplemented with grid electricity during periods of peak demand [23].

Fig. 1. Pads for EV fast charging station [24].

A standard PV power facility designed for EV charging stations would incorporate several key technical specifications [24, 25]: PV capacity ranging from 500 kW to 1 MW for urban centers [25]; battery storage banks rated between 1–2 MWh to enable overnight charging [25]; integration of wireless charging pads directly powered by solar-fed DC sources; and PV module efficiencies in the range of 18-22%, optimized through maximum power point tracking (MPPT) [25]. Figure 1 depicts an innovative wireless EV charging pad for parking spaces. This eliminates the need for setting up separate charging station infrastructure in cities and highways [24]. This method also reduces the problem of congestion at charging stations since an EV can easily be charged at any convenient parking space. Wireless electrical charging systems are much safer for cities in third world countries as well as being less prone to vandalism.

C. *Inductive Wireless Power Transfer*

Inductive coupling represents a non-radiative near field technique for wireless power transfer (WPT), employing Faraday's law of induction [21, 26]. One of the primary challenges in implementing wireless EV charging is overcoming the spatial separation between the vehicle and the charging unit, while ensuring precise alignment during parking to maximize energy transfer efficiency [26]. Remarkably, in 1999 an advanced inductive coupler was developed that demonstrated 97% efficiency at an output of 8.3 kW, despite maintaining a 3 mm air gap between the transmitting and receiving coils [14].

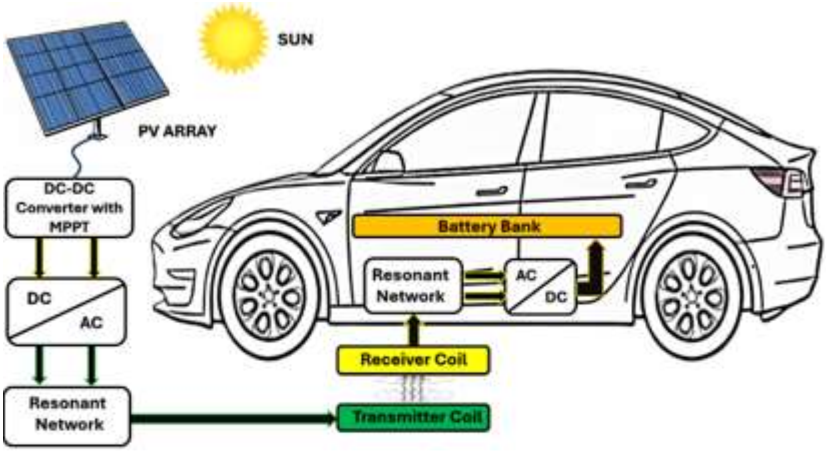

Fig. 2. Block Diagram of a Solar based IPT EV Charging Station.

IV. DESIGN OF A DC FAST CHARGER

In IPT illustrated in Fig. 2, provide many benefits including ease of use, and protection against vandalism [13]. In WPT configurations driven by an AC source, the rectifier stage delivers a DC output, which must be reconverted to AC to establish a time-varying magnetic field as shown in Fig. 3 [21]. This conversion is performed by a full-bridge inverter. The resulting current through the primary coil produces an alternating magnetic field, which in turn induces voltage in the secondary coil [8, 14, 21]. The induced voltage is rectified by a full-bridge circuit, enabling current to supply the load connected at the system's output [7].

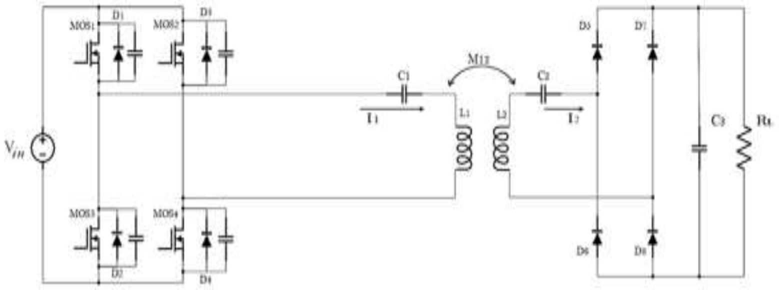

Fig. 3. Schematic Diagram of an IPT System [7].

The required design steps for an IPT are itemized in Figure 4.

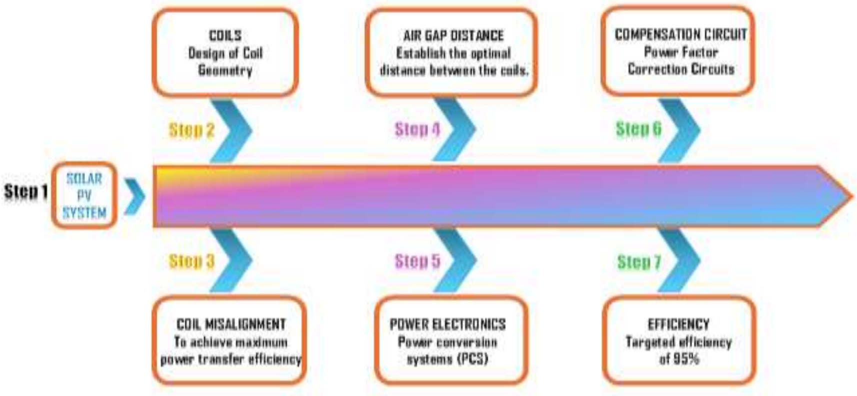

Fig. 4. Design Steps for a Solar based IPT System [7].

A. *100kW PV System Design and Sizing*

The capacity of the PV system for a fast EV charging station (Fig. 5) can differ greatly. Proper sizing requires evaluating factors such as the charger's power rating (50-350 kW), the total number of chargers, expected charging demand, and the inclusion of battery storage or grid connectivity to ensure reliability and manage peak loads [4, 5, 21].

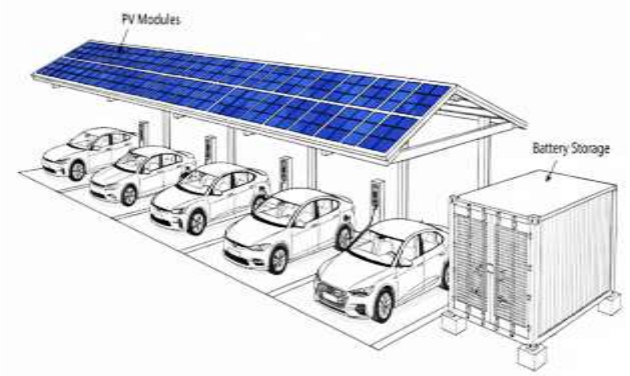

Fig. 5. PV Off grid EV Charging Station [36].

According to Rasha Kassem et al., the daily energy requirement for electric vehicles (EVs) is estimated at about 300 kWh, assuming 10 EVs each consume 30 kWh per charge [27]. A solar PV installation rated at 100 kW DC would necessitate roughly 182 panels, with each panel producing 550 Wp [27]. In Zambia, optimal installation involves positioning panels at a 15° tilt facing north [27], where annual solar irradiance ranges between 1900 and 2100 kWh/m² (equivalent to 5.2-5.8 kWh/m² per day) [27]. Under high irradiance conditions, the PV system supplies energy directly to EVs, while excess generation is stored in the battery energy storage system (ESS). When solar output is low, the ESS discharges to maintain charging, and if the battery's state of charge (SoC) falls below a set threshold (e.g., 20%) [27], grid support is engaged where available.

B. *Inductive Power Transfer (IPT)*

Methods of wireless charging for EVs are [21]: (a) inductive power transfer (IPT), Figure 6, (b) conventional capacitive wireless power transfer (CWPT), and (c) magnetic wireless power transfer (MWPT). The efficiency of wireless power transfer (WPT) diminishes when the air gap exceeds the coil's diameter or when the coils are misaligned. The effectiveness of energy transmission is primarily influenced by the coupling factor.

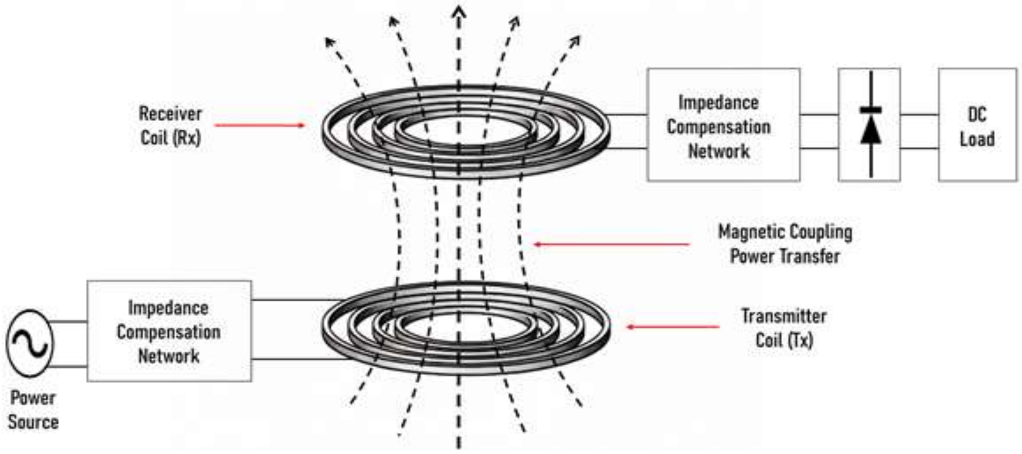

Fig. 6. IPT-based Charging System [21].

C. *Compensation Topologies*

Composition topologies are used in IPT to counteract the high leakage inductance of loosely coupled coils and achieve power transfer efficiency. There're four compensation topologies in IPT, namely [27]: Series-Series (SS); Series-Parallel (SP); Parallel-Series (PS); and Parallel-Parallel (PP). The inductances and capacitors are determined to cancel the reactive part of the transferred power.

D. *Design Modelling of an IPT System*

An IPT simplified circuit is shown in Fig. 7 [27]. The input and output voltages are denoted by *VP* and *VS.* The induced and reflected voltages in this model are described in terms of mutual inductance *M*, angular frequency ω, and primary and secondary currents *Ip* and *Is*. The magnetic coupling coefficient is related to mutual inductance, (Eq. 1). The reflected impedance *Zr* from secondary to primary can also be calculated (Eq. 2), [21, 30]. Where, *Zs* is the secondary system's impedance.

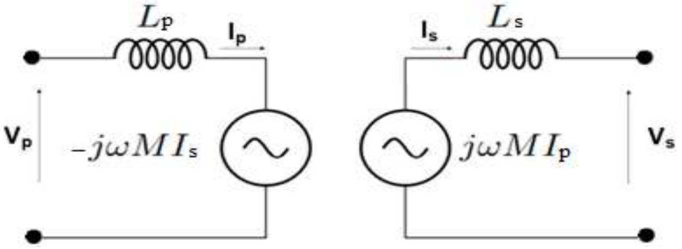

Fig. 7. Simplified circuit model of the IPT [21].

$$k = \frac{M}{\sqrt{L_p L_s}} \tag{1}$$

$$Z_s = \frac{\omega^2 M^2}{Z_r} \tag{2}$$

$$I_s = \frac{j\omega M I_p}{Z_s} \tag{3}$$

$$V_p = j\omega L_p I_p - j\omega M I_s \tag{4}$$

$$V_s = j\omega M I_p - j\omega L_s I_s \qquad (5)$$

$$\omega = \frac{1}{\sqrt{C_S L_S}} = \frac{1}{\sqrt{C_P L_P}} = 2\pi f \qquad (6)$$

$$P_{primary} = V_p I_p \qquad (7)$$

$$P_{sec\,ondary} = V_s I_s \qquad (8)$$

$$\sum_{i=1}^{n} Z_{ri} = n\frac{\omega^2 M^2}{Z_s} \qquad (9)$$

$$k_n = k\sqrt{n} \qquad (10)$$

$$o \leq k \leq 1 \qquad (11)$$

$$M_n = M\sqrt{n} \qquad (12)$$

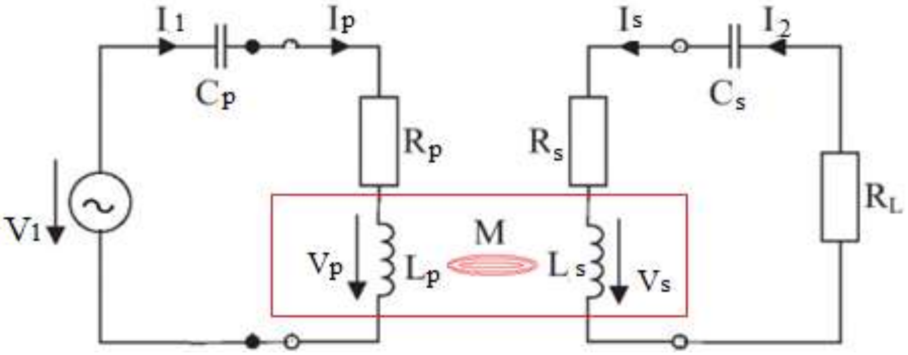

Fig. 8. Modelling of a Series-Series (SS) topology.

Figure 8 shows the most applied topology which is the SS architecture. Studies indicate that $L_a = L_p - M$ and $L_b = L_S - M$, representing the leakage inductances of the primary and secondary windings, respectively [13, 14]. The primary voltage of the coil is denoted V_p in this model, and it is supplied by a sinusoidal voltage source denoted V_1. Eq. (13) depicts the power consumption when a resistive load is attached, taking the mutual inductance parameter as a function of the primary current into account. Eq. (14) expresses the impedance of the primary coil. The equivalent primary current can be calculated as in Eq. (15).

$$P_{power} = {I^2}_p\left[\frac{(\omega M)^2}{R_L}\right] \qquad (13)$$

$$Z_1 = \frac{(M\omega)^2}{j\omega(L_b + M) - \frac{1}{\omega C_s} + R_s + R_L}$$

$$+ j\omega(L_a + M) - \frac{j}{\omega C_p} + R_p \qquad (14)$$

$$I_1 = \frac{V_1}{Z_1} \qquad (15)$$

Using Eq. (17), the total energy harvested of the WPT system can be calculated. The system efficiency is given by Eq. (19). In Eq. (19), RL is the secondary-side load impedance. The load and internal impedance are constant when the charging system is definite. As a result, it is possible to deduce that the system efficiency is solely determined by mutual inductance between the primary and secondary side coils [14].

$$C_p = C_s = \frac{1}{\omega^2(L_b+M)} \tag{16}$$

$$\eta = \frac{|\overrightarrow{I_2}|R_L}{|\overrightarrow{I_p}|^2 R_p + |\overrightarrow{I_s}|^2 R_s + |\overrightarrow{I_s}|R_L} \tag{17}$$

$$\frac{|I_p|}{|I_2|} = \frac{R_s+R_L}{\omega M} \tag{18}$$

$$\eta = \frac{R_L}{R_L+R_s+\left[\frac{R_p(R_s+R_L)^2}{(\omega M)^2}\right]} \tag{19}$$

V. FINDINGS AND DISCUSSION

The present literature shows that on average, an EV on full charge will have a range of some 400Km with a battery state of charge limit set at 20% which is considered optimal for battery health and charging speed which typically take 20~30min [31]. Table 1 shows the comparative summary of some of the EV models on the market in terms of range [32]. The premium model EVs such as the Tesla model 3, generally have a higher range than the new entry level cars.

Table 1. Range for EVs on the Market [32].

Model	**Battery (KWh)**	**Real Range (Km)**
Tesla Model 3	75	550-580
Hyundai Ioniq 5	77	420-480
Volkswagen ID.3	58	330-370
Renault Zoe	52	270-320
Nissan Leaf e+	62	320-350

This means that a typical rural route in Zambia such as the Lusaka to Chipata's great east road (Fig. 9) which has a distance of just under 600Km, will have a certain number of charging stops which can be calculated.

Fig. 9. 584Km Great east road (Lusaka to Chipata).

If the vehicle has a total range of 400 km on a full (100%) charge we can calculate the total number of charging stops required [33]. If we set the state of discharge (SoD) limit as 50%, meaning the vehicle must be recharged when the battery level reaches no less than 50% capacity, the usable distance for each segment of the

the journey is 50% of the total range. We can therefore calculate the usable range as in Eq. 20 [33]:

A. *Usable EV Range*

$$\text{Usable Range} = \text{Total Range} \times \text{SoD Limit} \tag{20}$$

$$\text{Usable Range} = 400\text{Km} \times 0.5 = 200\text{Km}$$

B. *Number of Journey Segments*

To determine how many segments, the 600 km journey is broken into, we divide the total distance by the usable range per charge as in Eq. 21.

$$\text{Number of Segments} = \text{Total Distance} \div \text{Usable Range per charge} \tag{21}$$

$$\text{Number of Segments} = 600\text{km} \div 200\text{km}$$

$$\text{Number of Segments} = 3$$

C. *Determine the Number of Charging Stops*

The number of charging stops is one less than the number of segments, as the final destination is reached at the end of the last segment without needing another stop as in Eq. 22.

$$\text{Number of Charging Stops} = \text{Number of Segments} - 1 \tag{22}$$

$$\text{Number of Charging Stops} = 3 - 1 = 2$$

Therefore, based on the assumption of a 400 km range EV, two charging stations would be required along the 600 km great east road route to maintain the 50% state of discharge limit. The charging stops would occur at approximately the 200 km and 400 km marks.

D. *Cost of PV powered DC fast Charging Station*

Assuming government incentives are active we generally would need to factor in the following in the design: Land acquisition, PV power plant, Type of chargers, Charger manufacturer, charging station software, Site preparation (excavation, plumbing, and concrete), Utility service upgrades, Labor, Permits and Licensing [34]. DC fast chargers are industrial grade charging stations which uses a 480-volt direct current to charge a car fully in about 30min [34,35]. Equipment charges and upgrades to infrastructure make DC fast chargers the most expensive, at around 50,000 USD which is about 1,000,000 ZMW as at January, 2026 [35].

VI. CONCLUSION

- The number of charge points at a charging station determines the number of vehicles that can be charged at that station at any given time. This means to service as many cars as may be required along the route without creating queues, there may be need to have several charging stations and charging point along the route. Government can incentivize the private sector to take up the challenge of creating the charging infrastructure which will help in job creation in the rural areas.

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