Novel Cruise Speed Highway Charging of Electric Vehicles in India

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ABSTRACT

The utility of all-electric automobiles is limited by various factors. The most important one is the 'range anxiety'; this is a severe limitation on the adoption rates of battery electric vehicles (BEV). There is a periodic need to stop and re-charge or replace the batteries after traveling a relatively short distance. The long time needed to recharge the depleted battery usually necessitates exchanging the battery for a different one at each charging stop, similar to changing horses on a 19th century Stage Coach.

Today three levels of recharging are available. Level 1 is using a home electrical system, taking roughly 8 hours to recharge the batteries after depletion at maximum range. Level 2 is charging from a commercial station, taking about 2 hours. Level 3 is high-current charging, which can complete the charging process in 30 minutes. Even Level 3 compares quite unfavorably to the 5 to 10 minutes needed to refill an automobile gasoline tank. Moreover, charging stations are not widely available outside major urban areas.

for a few hours at highway speeds, are quite prohibitive. Obviously, these are major obstacles in increasing the market viability of electric automobiles. The issue addressed in this paper is an approach using emerging technologies to overcome the limitations of a BEV. With the current battery technology, the mass and volume needed to carry enough charge to travel.

We address these issues by looking at the feasibility of charging automobiles while they are traveling at highway speeds. If this system is implemented, a BEV's effective range could be increased to match the range of an internal combustion engine (ICE) vehicle. This would imply that BEVs would be suitable for intercity highway travel, with the assurance of power being available on the go. We developed a model to optimize the number of wireless charging stations required depending on various factors. This model is discussed in detail later in the paper. As seen below, the requirement boils down to delivering roughly 1 kWh per charging station, while the automobile is moving at highway cruise speeds.

***Keywords**: Electric automobiles, battery electric vehicles, commercial station, charging station*

1. INTRODUCTION

In order for consumers to adopt BEVs, they must switch from the well established technology of ICE vehicles. For this consumers must appreciate the benefits of BEVs far in excess of the uncertainties involved in adopting the new technology. We expect rational consumers will be indifferent between a ICE vehicle and a BEV with 'infinite range'. Since our approach to increasing the range of a BEV involves emerging beam power technology, the best way to estimate the market sizing would be a bottoms up approach. In this market estimation approach, the number of vehicles required on the grid is backed out by setting a break even period for the investment. The model is a free cash flow analysis of the investments and revenues earned, to yield the net present value. The number of cars required on the

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grid is a variable which determines the NPV at the end of a set period.The following are the assumptions on which the computations are modeled.

2. WIRELESS VEHICLE CHARGING

There are two US Patents dealing with different aspects of wireless vehicle charging.[1] describes power transfer using ultrasound.[2] describes a wired charging device that uses a wireless communication to convey vehicle and charging parameters. Wireless charging of electric vehicles using inductive chargers cites 30kW levels [3] provides a summary Japanese perspective. Power beaming between antennae at two fixed points has been shown since the early 1900s [4], and taken much further using microwaves . Power delivery to UAVs and space vehicles has been studied using microwaves, and more recently, using lasers, microwaves and millimeter waves mitters. Each highway lane at such a charging station will have transmitters sized to lock on to 4 to 5 automobiles at a time, depending on expected traffic density and speed. Charging stations are expected to be set up every 4 to 5 kilometers. Power delivery to these stations may be through usual electric power grid, with converters to the beaming frequency set up at each charging station, or the power may be delivered as millimeter waves through waveguides, for direct feed to the transmitters.

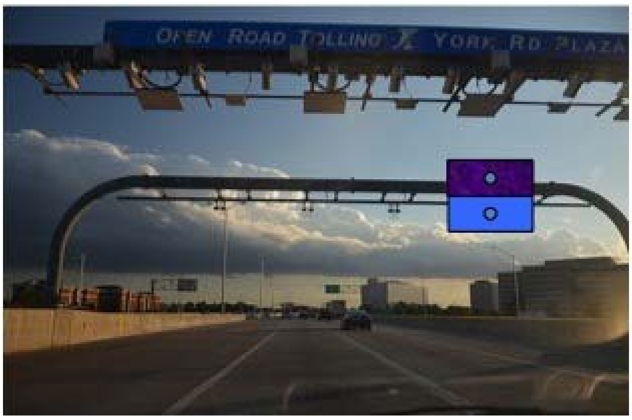

Fig.1. A Car approaching a highway charging station

The infrastructure to communicate with vehicles and to conduct financial transactions automatically, is already wellestablished. Modern cruise lane toll collection is able to assess tolls to fractions of a dollar, based on distance traveled in the toll lanes. To do this, toll systems already connect to cars as they approach, collect information from the vehicle, and inform the system in the vehicle of how much is billed. In the case of the EV cruise charging system, the communication system must also determine whether and how much the vehicle needs charging, the precise position and trajectory of the vehicle and the alignment of the phase array antenna and the vehicle antennae, the handoff from one antenna to the next as the vehicle approaches, the appropriate power transfer profile. It must monitor the signal return to verify that there is no interruption of the beam, as a safety check.

3. PROPOSED BASELINE SYSTEM OF ELECTRIC VEHICLES IN INDIA

Let us consider a conceptual architecture for such charging, modeled on wireless toll lanes that have appeared in several US states, where frames set up over highway lanes exchange signals with windshield-mounted modules, conducting financial transactions at highway speeds and acquiring high-resolution images if needed. The charging station adds millimeter wave antennae facing in both directions, beaming power to a forward-facing antenna as the vehicle approaches over a distance of 500 meters, and to a rearward-facing antenna as it recedes for 500 meters.Phase array technology will minimize antenna motion. Several independent antennae can operate from one array, which could be integrated with information signboards so that a 220 GHz transmitter has an effective diameter of 5 meters. The needed charging rate rises with vehicle speed at the rate of 2.5kW per kmph of speed. Thus charging while driving at 110 kph requires a charging rate of 275 kW, for the 18 seconds of charging time available, implying a millimeter wave intensity of nearly 400 kW/m2. These are for a 5-mile (8km) spacing between charging stations, and come down in direct proportion to the spacing. Buses and trucks would move slower through special charging lanes. Peak throughput in express lanes has been found to be 1600 cars per hour , but in tight groupings the interval between cars may be down to 0.75 seconds.

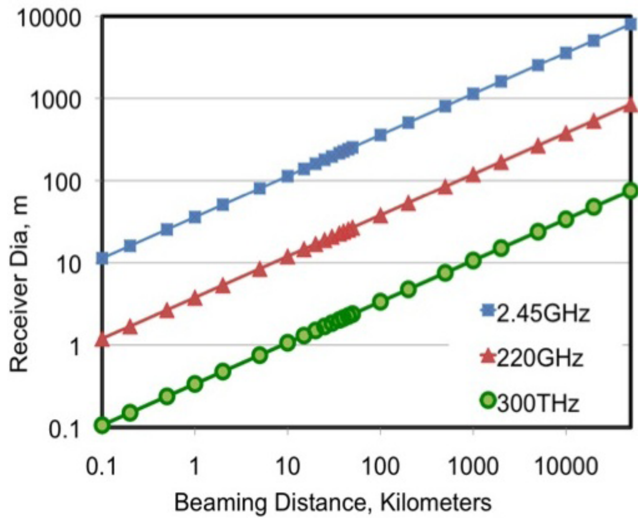

Fig.2. Receiver Dia Vs Beaming Distance, for Different Frequencies

4. DEVELOPMENT USING MILLIMETER WAVE TECHNOLOGY

Developments towards using millimeter wave retail beaming are surveyed by Komerath et al [5]. The rapid advances in 77 GHz radar, where some designs are based on 220GHz components, indicates promise. The mass needed per unit power is far less of a concern in this ground-based application than it is in applications based on Space or Lighter-Than-Air platforms.This means that converters based on solid state components can be used here long before their mass is reduced and efficiency improved sufficiently to be used in Space applications. End-to-end efficiencies approaching 70 percent are already feasible, we believe, using 220 GHz beaming, for the phases of conversion to,beaming and conversion from 220 GHz, given the short distances of beaming. Thus we anticipate that applications such as Cruise Charging will become drivers of this technology. Atmospheric transmission of millimeter waves is an issue that requires much more study. Transmittance data vary depending on the data collection sites and atmospheric conditions [6,7]. Beams of wavelengths 2.14mm (140GHz) and 1.43 mm (210GHz), respectively, have very high transmittance at the dry and polar conditions. So 140 and 210 GHz would be of interest for power beaming applications and 210 GHz would be preferable because it will lead to smaller receiver size. Although transmittance at 220GHz is less than that at 210 GHz according to these data, the choice of 220 and 223 GHz made in several military systems suggests other advantages. Horizontal propagation of millimeter waves is costly at low altitudes, as there are substantial losses. In the cruise charge application we believe these losses are acceptable since the beaming distance is less than 1 kilometer, and the higher price charged to account for these losses is justified by the convenience of highway-speed charging. Studies show that 92 percent of vehicles are actually parked during the times of peak electricity demand. Beaming power from a parked vehicle to a grid-connected or stand-alone receiver has been considered as a means to alleviate rolling blackouts or demand peaks, serve as spinning reserves, or provide regulation services, the last being found to be the most promising application. Once power beaming to vehicles is available, the vehicle antenna can serve as the means for sending emergency power to communities where the main power grid is downed by natural disasters, or indeed to alleviate stress on the wired grid during peak times.

5. CONCLUSION

The possibility of charging electric vehicles(EV) while they are cruising on highways is explored. Such a technology would break through the ‘range anxiety’ barrier to mass adoption of EVs. Developments in emerging energy technologies for automotive radar and other applications, have made possible the implementation of wireless millimeter wave beamed power. The rapid advances in the ability to accurately beam and receive power in the 70 to 225 GHz frequency range using solid state components suggests that it will become possible in the near future to beam sufficient power to perform such charging applications. Unlike short-range wireless inductive charging, beamed cruise charging is aimed to work on vehicles traveling as fast as 100 kph on straight segments of the highway, similar to cruise toll lanes used today. Subsequent versions may use aerostats or towers to beam power, enabling power delivery on curved roads in mountainous regions. The paper will survey related prior work and set out preliminary sizing and business case calculations, followed in the final paper by trade studies to perform a first level optimization. We also discuss the architectural requirements, charging rates and perform a sustainability.

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