NET-ZERO CARBON CHARGING STATIONS MATHEMATICAL MODELING WITH RENEWABLE ENERGY INTEGRATION

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***Abstract*—This research proposal is aimed towards the development of charging stations which are powered by renewable energy sources. The two sources used to replace traditional fuels are the wind turbines and solar photovoltaic cells. The goal is to perform mathematical analysis for economical and eco-friendly charging station for electric vehicles. With the increase in use of electric vehicles, the use of EV chargers also increases, and enough chargers should be available throughout the globe for promoting this trend. The EV chargers are powered through grids and conventional energy synchronized with wind turbine, solar power and battery packs. The solar and wind energy provide the energy to the EV charger for charging of battery packs. But when they are completely charged or not in use, the excess generation is sent back into the local distribution system. This not only lowers the load on our distribution system but also reduces the losses experienced from GENCOs to DISCOs. The reverse metering is also enabled to earn from the investment. Through this no generation is wasted and we can get credit from the electricity company. The wind and solar power are not constant and vary according to the location and time, so a model is designed to optimize the system size for wind, solar and battery pack. The cost is optimized to keep the annual cost of the charging station to a minimum. A total of ten cities are chosen around the globe having different wind and solar characteristics. A mathematical model is prepared which estimates the source capacity. The simulation results justify that we can achieve zero carbon footprint for charging electric vehicles where sunny weather or winds prevail.**

***Index Terms* — Electric Vehicle (EV), Charging station (CS), Photovoltaic (PV), Optimization, Wind turbine (WT), Smart grids (SGs).**

I. INTRODUCTION

The atmosphere is struggling due to burning of fossil fuels by public. We can control this through limiting the use of combustion engines and by promoting green EVs. The fuel used in transportation sector is greater than 70% and only 5% is used by public transport. The search for eco-friendly transport means increases day by day and electric vehicles have been around for more than a century [1].

A. EV Vehicles

The EV vehicles are smart and have significantly low carbon footprint on the atmosphere. The main components of EV are battery, motor, transmission, power converters and charging equipment as shown in Figure 1 [2].

Different types of chargers are available which can be categorized as slow chargers, fast chargers, and rapid chargers.

B. Solar System

The on-grid system, the off-grid system, and the hybrid solar system are the three most popular types of solar systems [3].

C. Wind Turbines

As the name implies, wind turbines are used to harness wind energy and transform it into electrical energy. They are employed in windier coastal regions. They make for a reliable sustainable energy source. Vertical and horizontal wind turbines are the two different forms. Vertical wind turbines are what we use. According to axis direction, HAWT and VAWT are the two categories of wind turbine technology. The majority-dominating vertical axis wind turbine has its blades revolving on an axis parallel to the ground and is more widely accessible and more reasonably priced than vertical wind turbines. The blades of a wind turbine with a horizontal axis rotate on an axis that is parallel to the ground. HAWT is more efficient in generating electricity than VAWT in specific wind-related circumstances, such as when a horizontal axis with propeller blades has an efficiency of about 60%. However, VAWT can operate effectively in household settings and small wind projects, independent of the direction of the wind [4], [5].

D. Wind Power Curve

The primary issue with a wind turbine's output power is wind speed. The so-called power curve serves to present the output power of a wind turbine [6].

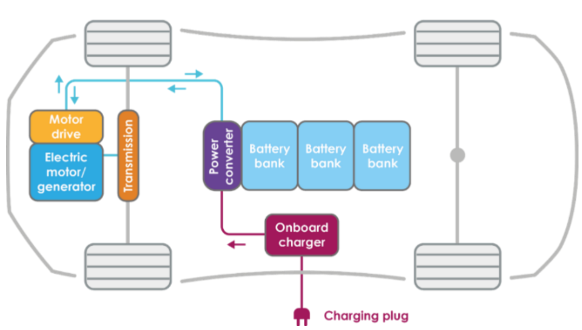

Figure 1 Internal Components of EV [2]

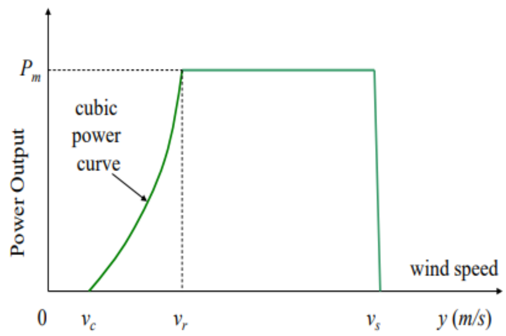

Figure 2 Wind Power Curve [7].

$$P_W(y_t) = \begin{cases} 0 & 0 < y_t < v_c, or\ y_t > v_s \\ \gamma y_t^3 & v_c \le y_t \le v_r \\ P_m & v_r \le y_t \le v_s \end{cases} \quad (1)$$

where Pm= m/v r3, rated power of the turbine is given by Pm v_c , v_r and v_s stands for the cut-in speed, rated and vs the cut-off wind speeds. The wind turbine used in this study features a 2.5 m/s cut-in speed, a 10 m/s rate speed, and a 25 m/s cut-off speed. Figure illustrates an equation for a conventional curve for the wind power with four functioning stages [7].

E. Weibull Distribution

Weibull distribution is a continuous probability distribution method first applied in 1933. It has multiple parameters which control the probability. The method can be used as density function, distributive function or for generating moments. Weibull distribution will be used to predict the weather conditions based on previous past weather data. The PDF of a Weibull random variable is [8].

$$f(x;\lambda,k) = \begin{cases} \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-(\frac{x}{\lambda})^k}, & x \ge 0 \\ 0, & x < 0 \end{cases} \quad (2)$$

The important consideration for a RE based charging station is implementation is the size of the facility, the location, the weather, the EVSE, as well as the administration and maintenance (O&M). The investigation also aims to assist the facility's owner create a grid- Renewable energy-powered networked distributed generation (DG) systems increase owner revenue while emitting no carbon dioxide. WT, PV, energy storage, and a net metering scheme make up the DG system. What matters most is the battery system, solar PV panels, and WT capacity. The output of WT and PV are not guaranteed because to the unpredictable nature of wind and solar producing respectively. The optimum compatible capacity of WT, PV, and battery is determined using a mathematical model that replicates the power produced by the WT and PV systems on hour by hour over a 20-year period to lower the annualized charge station cost [9].

II. PROBLEM STATEMENT

The EV charging stations are high power consuming devices, and the electricity requirements depend on many factors. The aim of the net-zero carbon EV stations can be estimated through the mathematical model which will tell us about capacity of renewable energy required to be completely independent of local grid.

III. LITERATURE REVIEW

EV charging scheduling for parking spaces integration solar system and batteries was optimized using improved algorithms. The experimental results show that the presented scheme can improve the utilization of PV system and reduce operating costs. The short-term power production is used to make decisions. Better results were achieved as compared to other algorithms [9].

In the past few years, due to the increase in number of public EV chargers, the unbalancing of distribution system is faced. This is resolved using the probability. The driving characteristics and charging window declare that we can avoid congestion and unbalancing [10].

Nikita et al. observed the impact of electric vehicles on electric grid. The potential in electric vehicles competed with ICE (Internal Combustion Engine) vehicles. The competition of these, the costs, maintenance and other factors are discussed concluding that we can have an even larger number of electric vehicles in future [11]. The authors have analyzed the benefits of EV as compared to the ICE technology. The technology and the advantages of EV, the batteries and its types are also discussed deeply. The use of EV in smart cities will help reduce the load from local grids. The EV will adopt different charging strategies to make deployment of EV easier [12].

A model of redesigned EV charging station is proposed for fast charging. The equipment has close to unity power factor and almost zero harmonics. The coordinated operation of renewable energy makes it more beneficial and minimize DC-DC conversion losses [13]. The paper proposes optimized strategy for sizing of battery energy storage system. The mathematical model required by the electricity depends on the charging level and how many cars are being charged at a single time. So, we must decide among cost, efficiency, range and power [14].

The mathematical model is proposed to get P-Q curves according to our grid. The output is dependent on many factors and parameters such as irradiance, shadow effect, temperature, climate, and weather data [15]. The era of the accurate voltage of ac below conditions of the unbalanced voltage of dc is made by using extended superior three-stage vector unbalanced technique of modulation with a theoretical framework which has been proposed. The electricity float manages between solar PV with simultaneous MPPT operation, battery, and grid system with a unique algorithm of manipulate for the proposed system has also been made. The simulation results are used to check the overall performance of the proposed topology and to manage algorithm. The ac-facet current control with battery charging and discharging currents at distinct solar irradiance stages are described inside the effects of the proposed gadget. Control of solar photovoltaic device with battery energy garage device in transmitting electricity into ac grid is performed

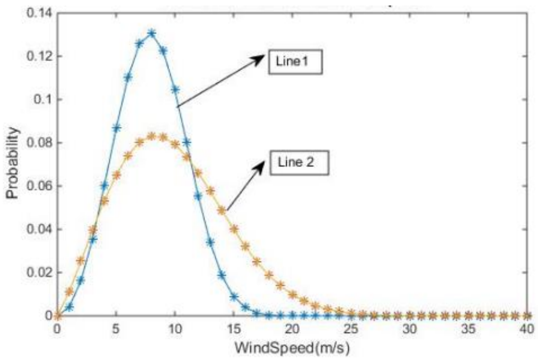

Figure 3 Weibull Distribution [21]

successfully by means of the proposed topology [16].

This study tested the European variable RE integration challenges associated with the power capacity. The power potential of desk bound storage technology is also analyzed. The dedication of the storage fractions, the electricity capability, and the power garage capacity had been modelled in a brand-new context. Based on the consequences we got here to the belief that because of the requirement of a cozy electricity supply, all elements are similarly essential for a success vre integration. The outcomes showed that achieving at least approximately 45–50% penetration until 2040 may be a sensible goal in the European electricity grid quarter. The DG situations appear to be rational goals. For the GCA situation, a 55 % vre penetration fee seems possible in comparison to the 59% goal. For the fulfillment of European vre integration, electricity garage marketplace developments and regulations that inspire the expanded use of energy garage structures are vital [17].

To increase energy efficiency in grid-connected wind generating systems and with load, the research provides a STATCOM-fuzzy based control technique. Simulated functioning of the STATCOM /BESS manage device built in MATLAB to prevent electricity loss. It can remove the harmonic components of today's strain. It maintains the supply voltage and current in-segment and directs the reactive power demand for the wind generator and load at% in the grid device; as a result, it provides a chance to embellish the transmission line's intended use. The great overall performance has been proved by the combined wind technology and STATCOM. We model methods for achieving up to 100% renewable energy electric powered energy structures for the contiguous America to gauge the complexity of putting in place a fully renewable energy power system for the country. The least-fee buildout predicts that in 2050, re penetration will reach 57% under baseline conditions. For 80%, 90%, 95%, and 100% renewable energy, respectively, the average cost of lowering CO2 in comparison to this baseline scenario is $25, $33, 40, and 61 dollars per ton. The cost of the technology increases to $36 per MWh from $30 at 95% (achieved in 2040) and to $39 per MWh at 100%. The need for corporate renewable firm expertise finally drives the cost of additional abatement from 99% to 100% renewable energy to reduction possibilities of $930/ton. We examined 22 additional possibilities for a buildout of up to 100% in addition to the base conditions. These sensitivities cover unique generational trajectories, compliance requirements, timeliness of needs, electrification, and transmission accessibility. Nonlinear marginal expenditures had been determined for the final few percentages approaching 100% renewable energy for all sensitivity levels, which would stimulate various non-electric-sector abatement options. [18].

The approaches are used to compare the performance of rooftop and floating PV systems, especially modelling with PVSYST and mathematical computations. The pvsyst simulation shows that a rooftop PV system has an overall performance ratio of 82.69% compared to a floating PV device's 76.39%. The rooftop PV system's performance ratio is 73.41%, while the floating PV system's performance ratio is 80.24%. Differences in the performance ratio findings are brought on by the mathematical calculation's exclusion of the back side of the bifacial floating PV panels and the pvsyst simulation's inclusion of the heat produced by the concrete beneath the rooftop solar PV system. To raise the performance ratio of the bifacial PV device, the surface's albedo price must be optimized. The largest PR values of the two systems differ by just around 2.45%, and the PR values of the two systems are similar. These results suggest that all systems should be equally suitable for installation in TOD sites, and implementation objectives should be based on the region's available resources. [19].

IV. Modeling Renewable energy production

Sources like wind, sunlight, biomass, geothermal, and tides are being researched as potential replacements for conventional coal, gas, and oil. Solar and wind power are precisely the two most important types of alternative sources of energy. They have been increasingly utilized in the last twenty years to meet the growing demand for energy.

If solar irradiance and wind fluctuation can be anticipated, cost effectiveness through mathematical models can be achieved. This would let us to choose the appropriate WT, PV capacity, and storage capacity for a certain charging station. Due to the variety of EVs being charged, the load is viewed as a variable parameter. It is required to predict and forecast the wind speed and weather based on past meteorological data to match the load.

A. Modeling Output of Wind Turbine

The presented system collects climatic data from Lahore, Phoenix, Toronto, Delhi, and London, over the last two years. There are a total of five cities. Among the information gathered by the national climate data center are averages for temperature, day length, solar radiation, and wind speed. The weather in these sites is typical and distinct in terms of sunny days and wind speed [20].

$$f(y) = \left(\frac{k}{c}\right)\left(\frac{y}{c}\right)^{k-1} e^{-(\frac{y}{c})^{k}} \tag{3}$$

$$F(y) = 1 - e^{-(\frac{y}{c})^{k}} \tag{4}$$

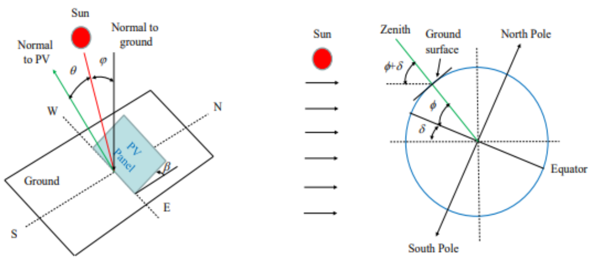

Figure 4 Factors Affecting the PV Generation [22].

We obtain the equation to determine the wind speed at t hours from the function above [21],

$$y = C * \sqrt[K]{-(\ln(1 - F(y)))} \quad (5)$$

B. Modeling Output of Solar PV

A technology known as solar photovoltaic captures solar radiance and transforms it into electrical power. In this section, we create simulation software to simulate a solar PV panel's annual output power at the designated sites. The size of the panels, the orientation, operating temperature, and tilt angle of the panels, the date, the incident solar irradiation, and the electric current on the panels are some of the variables that affect the power output of a PV system [22].

The actual output according to the weather conditions for a PV system can be,

$$P_t(s_t) = W_t \eta A s_t [1 - 0{,}005(T_o - 25)] \quad (6)$$

C. Battery Storage System

Battery packages come in a wide range of styles and dimensions. An actual fundamental unit acting as a chemical energy storage mechanism is the electric cell. Numerous electric cell units are connected in sequence based on the situation. One of the essential elements in this study endeavor is the battery. Due to variations in wind speed and weather, the battery capacity in the charging station may differ depending on the location. The first-generation battery, the lead-acid battery, has been around for almost 170 years. Since 1980, the market's leading technology has been the rechargeable lithium-ion battery. The storage system for the charging stations will be made up of lithium-ion batteries (also known as LIBs). This section will introduce LIB's operating system and parameters [23].

A rechargeable battery can only do two things: charge and discharge. Extra energy from PV and WT can be temporarily accumulated in battery bank if there is available capacity. On the other hand, if the load of the charging station is greater than the supply of renewable energy from WT and PV, the energy accumulated can be released to fill the electrical power gap. Here, two straightforward simulations for the charging and discharging processes are displayed.

V. CHARGING STATION AND EV

The history of electric vehicles (EVs) spans well over a century. The first electric motor suitable for industrial usage was created in 1834 by Thomas Davenport. In 1912, the first EVs were built. All electric vehicles (EVs) rely on electricity that is stored in a battery or group of batteries to drive the vehicle. However, the widespread discovery of crude oil and rising consumer expectations for long-distance travel caused the EV market to endure a severe decline in the 1940s.

Table 1: The Component rating of the system

	Output	Number	Working Hours
Rapid Charger (DC)	50 kW	2	24
Typical Charger (DC)	10 kW	4	24
Illumination	10 kW	5	12
Output	150 kW	11	60

The current resurgence of electric cars is mostly driven by concerns about climate change and advancements in battery technology (EV). Electric vehicles (EVs) are good for the environment and the economy. EVs can save 3.0 cents per mile compared to gasoline-powered automobiles (Rates of EV and ICE). The market for electric cars has lately seen a boom in development due to the improvement of technology, rising gas prices, and government policy support [24].

EVs are becoming more and more popular on the market as the automotive industry develops. Aimed at middle-class buyers, the Nissan Leaf, Honda Insight, and Chevy Volt have all shown success in the switch to a lower-carbon and gas-free mode of transportation. At the end of 2012, there were more than 180,000 EVs on the road. Japan topped the global market for sales of pure electric cars in 2018, with a 28% market share. The US came in second with a 26% market share, after China (16%), France (11%), and Norway (7%). Trigg et al., 2019 Plug-in electric vehicles (PEVs) will account for 2.8% of all new vehicle registrations by 2015, according to the 2018 National Automobile Dealers Association Report [25].

In terms of energy efficiency and environmental protection, electric vehicles (EVs) perform better than internal combustion engines (ICEs), but customers find them less appealing because of their lengthy charging periods and constrained driving range. The chemistry and size of the vehicle’s battery are frequently the answers to the first two problems. One of the key elements influencing an electric vehicle's performance and supporting the industry design standard is the battery. Lead acid, lithium-ion, and nickel-metal hydride batteries are all options for EVs.

A. Charging Capacity of a Station

All the charging stations are close to a neighborhood. Each charging station has a charge point that can accommodate two DC fast chargers and four normal DC chargers, each of which takes an hour to charge to 80% completion compared to the fast charger's 20 minutes. The 24 KWh lithium-ion batteries in the Nissan Leaf are used to store and power the motor. At level 3 charge condition and when using the charging station, it can be charged to 80% of its capacity in less than 30 minutes.

Table 2 Optimized Installed Capacities

Location	Case 1 (KW)	Case 2 (KW)		Case 3 (KW)		
	WT	WT	PV	WT	PV	Battery
Lahore	63.939	56.2163	15.7973	44.0855	15.0583	5.99125
Delhi	64.014	55.339	17.585	44.338	18.669	7.467
London	63.927	55.880	18.937	43.213	20.742	8.18
Toronto	63.914	57.222	1.352	44.999	2.369	0.947
Phoenix	63.901	56.424	25.315	43.792	18.453	7.371

According to the association of Japan's EV charging standard, the most widely used fast charger technology can provide 50 KW. As a result, 50 KW is used as the output of the quicker DC chargers in this article.

Three scenarios are used to calculate the cost of the charging station,

(1) charging stations that exclusively use wind energy as a energy source;
(2) combining wind and solar energy sources; and
(3) Installing onsite solar and wind energy sources through a grid-connected DG system

VI. MODELING SYSTEM

To satisfy the distributed energy resources (DG) design objectives, including cost, energy dependability, and carbon reduction. Any excess energy from PV and WT can be stored or sent to the main grid to generate additional revenue for the owners of charging stations under the feed-in tariff scheme.

We test our strategic approach in several areas under a variety of weather scenarios. Although the cost criteria are the same, variations in wind speeds and bright days may affect the best choice for WT, PV, and battery capacity.

Four different charging station designs are available:

(1) Integrating wind power
(2) Integrating solar photovoltaics
(3) Combining wind and solar PV
(4) Combining solar and wind power PV mix with backup batteries.

According to the organization of Japan's EV standard, the most widely used charging technique has a 50 KW output. At the Tesla supercharger charging station, the power of the charging station is 90 KW. After 30 minutes of charge, the car can go 240 kilometers. The DC fast charger is assumed to use a 50KW output in this section.

A. *Cost Analysis*

The system's costs also include the upfront investment, ongoing operating and maintenance expenses, income through surplus energy, and utility charges [23],

1. **Installation Cost**

$$C_{in}(P_1^c, P_2^c, P_3^c) = \emptyset(n,r)\sum_{i=1}^{N} a_i P_i^c \quad (7)$$

$$\varphi(n,r) = \frac{r(1+r)^n}{(1+r)^n - 1} \quad (8)$$

This parameter is unknown and needs to be improved because it is a choice variable. At a specific discount rate, the capital recovery factor (CRF) converts a stream of equal yearly payments from a present value (interest).

2. **Operations and Maintenance**

Even though solar and wind resources are free, operating and maintaining them involves two costs: (1) renting the space needed to install wind turbines, solar panels, and battery systems; and (2) repairing and maintaining wind turbines, solar photovoltaic systems, and battery systems because of component ageing and wear-out.

$$C_{om}(P_1^c, P_2^c, P_3^c) = \sum_{t=1}^{T}\sum_{i=1}^{N} b_i P_{it} \quad (9)$$

3. **Electricity Bill**

When the charge station is short on power to charge EVs, it must buy electricity from the main grid. Because WT, PV, and BS units can handle a big fraction of the electric load, the owner will save a significant amount of money on utility costs when he or she adopts onsite generating. The owner's real utility expenses are as follows:

$$R_{Ebill}(P_1^c, P_2^c, P_3^c) = \rho\sum_{t=1}^{T}(P_t - D_t)^- \quad (10)$$

with

$$P_t = \sum_{i=1}^{N} P_{it} \text{ , for } t = 1,2,3,\ldots\ldots,T \quad (11)$$

B. *Aggregate* Annualized Cost Model

The cost model that accounts for all the factors mentioned earlier. Keep in mind that the onsite DG system's installation, operation, and maintenance expenses are offset by carbon credits, revenue, and net metering income.

$$f(P_1^c, P_2^c, P_3^c) = \phi(n,r)\sum_{i=1}^{T} a_i P_i^c + \sum_{t=1}^{T}\sum_{i=1}^{N} b_i P_{it} + (\eta - \rho)\sum_{t=1}^{T}(P_t - D_t)^- - (\sum_{j=1}^{T}\sum_{i=1}^{N} c_i P_{ij} + q\sum_{t=1}^{T}(P_t - D_t)^- + \eta\sum_{t=1}^{T} D_t) \quad (12)$$

VII. SIMULATION AND RESULTS

The costs vary on four different models, but if a charging station relied solely on an on-site solar generator, the cost would be extremely high. Additionally, we must take into account how much land will be occupied. Phoenix, for instance, receives 5.47 KWh/m2 of daily solar energy. 1996.5 KWh/m2 is the total annual solar radiation. 24 KWh are contained in the Nissan Leaf's battery. CPV and RPV are respectively 40% and 10% efficient.

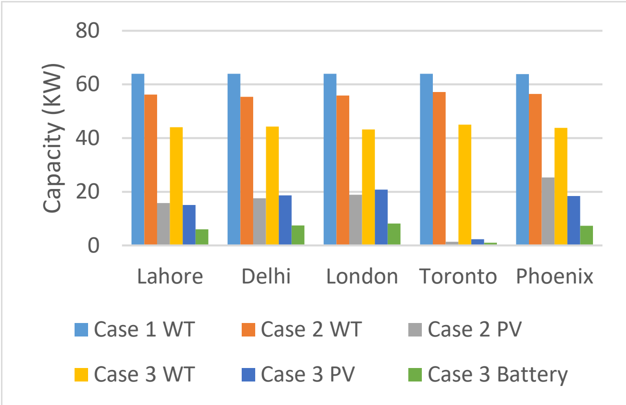

Figure 6 Graphical Representation of Table 2

Table 3. Cost of Project

	Case 1 (USD)	Case 2 (USD)	Case 3 (USD)
Lahore	8320474	10296410	9475258
Delhi	9120742	10517573	10034153
London	7815954	10629540	11443702
Toronto	7348532	7899324	6299208
Phoenix	8996667	12139202	10123968

The PV system's surface area is 24KWh x 10% x 5.47 = 43.9 m2 for PV and 24 x 40 x 5.47 = 11 m2 for CPV. For a charging station to fully charge a leaf in one day, 43.9 m2 or 11 m2 of solar panels are required. It is not feasible to use solar PV as the exclusive source of energy.

Consequently, this work merely simulates and estimates three factors. In scenario 1, the wind turbine is the only source of power for the charging station. In Case II, the charging station uses on-site generators made of a wind turbine and solar panels The DG system has a built-in charging station in Case III.

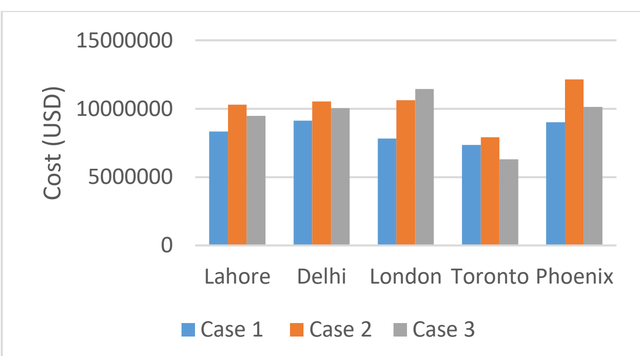

Figure 5 Graphical Representation of Table 3

An average of 50 % increase in profit is observed per KWh and justifies our proposed model is optimizing the cost and profits, generating best revenue at minimum investment.

VIII. CONCLUSION & FUTURE WORK

Incorporating wind and solar energy into the architecture of charging stations addresses the design concerns. A charging setup is specifically created to boost the revenue received by the

Table 4. Profits per kWh

	Case 1 (USD)	Case 2 (USD)	Case 3 (USD)
Lahore	0.160425	0.035725	0.04515
Delhi	0.0466	0.0208	0.0259
London	0.0401	0.015	0.0228
Toronto	0.08	0.1007	0.1017

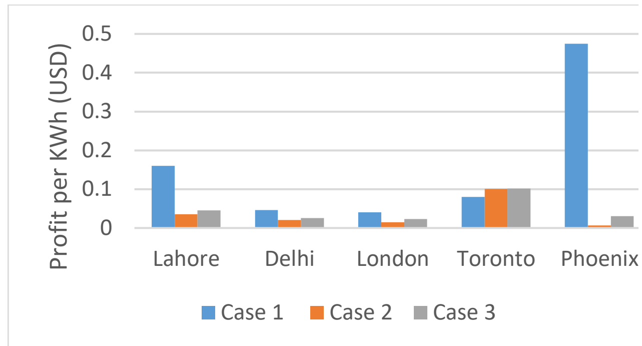

Figure 7 Profit Earned after Optimization

owner of the charging station through on-site wind and solar power. The simulation results show that it is possible to achieve net-zero carbon emissions by powering public charging stations entirely with on-site wind and solar energy resources. The weather at the station's location during its 20-year service period affects how profitable the charging stations are.

The short onboard driving ranges and prolonged charging times are the key challenges to the introduction of EV fleets. Most modern EVs can travel more than 100 miles on a single charge because of recent improvements in energy density and battery capacity. In actuality, the 85 KWh Model S can travel 270 miles on a single charge. Like a Tesla supercharger, the maximum output power of the charger grows and can reach up to 250 KW. As a result, the charging time can be drastically reduced.

A network of public charging stations should be implemented as part of the solution to the expanding EV fleet. Customers are not constrained by the size of the battery capacity when driving their vehicles between cities. The Tesla supercharger is a fantastic example of how to take such charging network expansion projects. Tesla wants to make its network of superchargers available to drivers in the United States and Europe without charging them a fee.

Building appropriate and system-wide charging stations is essential to removing customers' reservations about purchasing EVs and achieving the "true green" goal through the widespread use of electric vehicles. This is due to the increasing battery capacity. To achieve net-zero carbon emissions and achieve energy independence from fossil fuels, charging stations powered by renewable energy sources are needed.

A. The Smart Grid

The primary factors that affect the generation of renewable energy for nearby PV and WT apparatus are the wind speed and

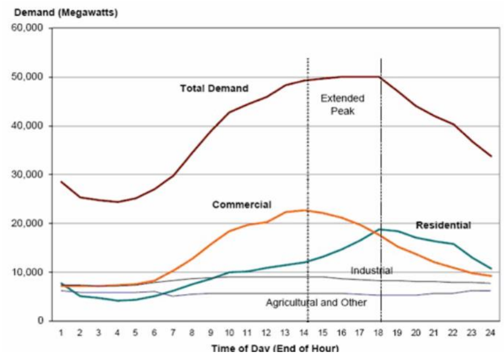

Figure 8 Load Profile of California

sun irradiation. Geography affects wind speed and direction, while climate affects solar radiation. By providing a variety of energy prices, the smart grid will be able to move consumption from periods of high demand to periods of low demand depending on fluctuating power availability. If the quantity of power generated locally is insufficient to fulfil demand, the system can use the main grid by selecting a low-cost period when a charging station's battery packs need to be charged.

B. Charging Station to Grid Energy Transfer

Vehicle-to-grid (V2G) technology is well known for transferring energy from electric vehicle batteries to the utility grid at times of peak demand and returning the energy to the vehicle during times of off-peak, low demand.

The load profile for all of California on a hot day in 2019 is depicted in the graph below. Between 14 and 18 PM, the daytime load doubles compared to the off-peak hours of 2 to 5 AM

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