Design of Carbon-Friendly E-scooter Charging Hub Powered by PV System with Extended Battery Life

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Abstract—Renewable energy is being more widely used, and its usage in transportation is becoming a need to minimize pollution. India produces a large number of scooters, and manufacturers are interested in producing electric scooters and emphasizing the need for charging stations along roads so that e-scooters can travel longer distances. The design of an e-scooter charging hub based on PV renewable energy systems is presented in this paper. A detailed simulation model with results is provided to analyze the station's efficient performance. Four chargers of different ratings are designed on a charging station, and a backup system with a large backup battery is connected to the circuit to provide energy on rainy or cloudy days as well as at night. Finally, a comparison is given to show the impacts of charging schemes impacting the overall e-scooter battery life span.

Keywords—e-scooters, battery, charging station, renewable energy

I. INTRODUCTION

Private and public transportation contributes significantly to environmental pollution, and electric vehicles are rapidly becoming the most essential mode of transportation for achieving a cleaner environment. Many countries are producing electric cars and scooters that are powered by various forms of energy. This study focuses on the Indian market for electric scooters, which are powered by renewable energy PV systems. The electric vehicle industry is growing in many countries, and electric scooters are becoming increasingly ubiquitous on the roads. However, there are various obstacles in operating electric traffic over long distances, which might be avoided by installing charging stations on roads and supporting traffic in covering long distances without losing battery charge, since charging stations help them in the most effective way [1-5].

Electric scooter market (ESM) growth in Asia is predicted to be 30% from 2022 to 2029, with a net price of $625 billion by the end of the period [6]. As investment in this area increases, battery prices continue to fall, assisting in the expansion of the e-scooter industry. Government policies aimed at reducing pollution, people's desire to contribute to a cleaner environment, and billionaires' and businessmen's investments are all contributing to the growth of the electric scooter market. Covid-19 has had an impact on growth in recent years, with growth being slower than in previous years. Due to lower battery prices, an increase in the number of rides, and government measures to promote e-mobility, ESM growth is expected to be significant throughout the projected period.

The charging station model is created using MATLAB simulation, which illustrates the whole function of the station and assists in understanding the expected life of the battery utilized in this study. The amount of electricity generated by the solar systems is analyzed, and is compared to the charging load. However, the backup battery system draws the stored energy of the current system. The charging station modeling findings are displayed as waveforms, which are then explained to help us understand how the model works.

II. PROJECT POTENTIAL INCUBATION

In India, over 150,000 motorcycles and e-scooters were sold in 2019, representing a 21% growth over the preceding five years. And by the end of 2025, the numbers are predicted to reach 1,080,500, with a compound annual growth rate of almost 58% for the five-year period. Furthermore, sales to individual consumers are expected to reach one billion dollars by end of this period, with a compound annual growth rate of 64%. Because of its vast population, India produces a lot of carbon and is the third-largest emitter of CO2 from fossil fuels. According to previous reports, India has the largest number of cities in the world that emit enormous amounts of pollutants and contaminate the environment. Out of thirty cities throughout the world, India has twenty-one polluting cities, as reported by IQAir in 2019 [6].

To combat pollution caused by autos, the government is taking strong measures and expressing its interest in growing the EV business. People in the country are also expressing an interest in riding e-scooters to help clean up the environment. Lithium-Ion batteries are being manufactured at a rapid rate in India, and the 48V battery is the most popular kind used in electric scooters, and its market share is expected to be quite high up to 85%. This research has a number of goals that will be accomplished at the end and some of them are explained below.

- Choose a reliable battery to obtain the optimum battery characteristics for e-scooter functioning, and after a thorough examination of the distance covered in a single full charge of the battery, market prices, and availability, a 48V and 24Ah capacity is chosen.
- Choosing the appropriate number of solar panels to generate the required power is also a challenge.
- Select a backup battery with the necessary characteristics.
- Design chargers with the same 48V voltage but different current values depending on how quickly the battery needs to be charged.
- Determine the battery's discharge current, which will power an electric scooter's motor.
- Finally, calculate the battery's average lifespan to determine how long it will last.

These were all the study objectives, however, there are other long-term achievements to reach, and some of them are included below.

- The primary goal of the research is to make a pollution-free environment.
Increase the viability of current electric scooters by installing charging stations based on solar panels along their routes.

Save money and extend the range of distance covered by scooters.

Provide advice to governments on how to change existing policies to favor renewable energy.

First, choose the battery type and e-scooter power range before designing the charging station. In the present market of electric scooters driven by grid electricity, there are many varieties of e-scooters that cover varied distances and may be recognized/distinguished/identified based on their covered distances, price, and required power.

As shown in Table I, the price is given in British Pounds and is derived mostly from the Indian Rupee market. These bikes cover distances ranging from 56 to 90 km [7]. However, one thing to keep in mind is that all of the aforementioned e-scooters run on grid electricity. Because this station uses solar PV systems, the cost of installing them on the station has an impact on the project's value. So, after comparing various types of e-scooters and keeping prices in mind, as well as comparing them to a reliable range of distance covered, it is proven that the 1.20 kW electric scooter can cover an efficient distance, as well as having a low price and being recharged with less power than others. Furthermore, while several experiments have been conducted in the past to operate an electric scooter with a 400-watt motor, the chosen scooter has much power and is easily accessible in the market. Several electric scooter batteries are also examined in terms of cost and capacity.

### TABLE I. ELECTRIC SCOOTERS' CHARACTERISTICS [7]

<table>
<thead>
<tr>
<th>NO</th>
<th>Model of e-scooters</th>
<th>Range/Charge of e-scooters</th>
<th>Power Ratings (KWh)</th>
<th>Prices Rupees (₹)</th>
<th>Prices Pounds (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bajaj Chetak</td>
<td>90 km</td>
<td>2.98 KWh</td>
<td>₹142,600</td>
<td>£1452.28</td>
</tr>
<tr>
<td>2</td>
<td>Ampere Magnus STD</td>
<td>85 km</td>
<td>1.15 (60V, 28Ah)</td>
<td>₹68,000</td>
<td>£692.53</td>
</tr>
<tr>
<td>3</td>
<td>Pure EV e Trance</td>
<td>62 km</td>
<td>1.10 KWh</td>
<td>₹52,000</td>
<td>£529.58</td>
</tr>
<tr>
<td>4</td>
<td>Okinawa R30</td>
<td>58 km</td>
<td>1.24 KWh</td>
<td>₹56,400</td>
<td>£574.39</td>
</tr>
<tr>
<td>5</td>
<td>Ampere Reo</td>
<td>65 km</td>
<td>1.10 KWh</td>
<td>₹57,000</td>
<td>£580.50</td>
</tr>
<tr>
<td>6</td>
<td>Ben ling India Ion</td>
<td>62 km</td>
<td>1.30 KWh</td>
<td>₹58,000</td>
<td>£590.69</td>
</tr>
<tr>
<td>7</td>
<td>Hero Electric Flash</td>
<td>57 km</td>
<td>1.25 KWh</td>
<td>₹55,000</td>
<td>£560.13</td>
</tr>
<tr>
<td>8</td>
<td>Okinawa Lite</td>
<td>56 km</td>
<td>1.24 KWh</td>
<td>₹59,900</td>
<td>£610.04</td>
</tr>
</tbody>
</table>

As shown in Table II, different types of batteries are discussed, along with their nominal voltage, capacity, and price in both British pounds and Indian rupees. The essential power for the aforesaid e-scooter may simply be taken from a 48V battery with a capacity of 24Ah. This is the most widely accessible battery in India and the most reliable figure for riding an e-scooter. Following the aforementioned thorough study and complete analysis, a 48V battery with a capacity of 24Ah is selected for use in this project's e-scooters.

### TABLE II. ELECTRIC SCOOTERS' BATTERIES CHARACTERISTICS [8]

<table>
<thead>
<tr>
<th>NO</th>
<th>Battery Model</th>
<th>Nominal Capacity</th>
<th>Nominal Voltage</th>
<th>Prices Rupees (₹)</th>
<th>Prices Pounds (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LiFePo4 Battery Pack</td>
<td>30 Ah</td>
<td>72 V</td>
<td>₹32,000</td>
<td>£325.43</td>
</tr>
<tr>
<td>2</td>
<td>Lithium Ion Battery Pack</td>
<td>25 Ah</td>
<td>59.2 V</td>
<td>₹21,000</td>
<td>£213.56</td>
</tr>
<tr>
<td>3</td>
<td>LiFePo4 Battery Pack</td>
<td>30 Ah</td>
<td>48 V</td>
<td>₹21,000</td>
<td>£213.56</td>
</tr>
<tr>
<td>4</td>
<td>Lithium Ion Battery Pack</td>
<td>30 Ah</td>
<td>48 V</td>
<td>₹21,000</td>
<td>£213.56</td>
</tr>
<tr>
<td>5</td>
<td>Lithium Ion Battery Pack</td>
<td>28 Ah</td>
<td>48 V</td>
<td>₹20,500</td>
<td>£208.48</td>
</tr>
<tr>
<td>6</td>
<td>LiFePo4 Battery Pack</td>
<td>28 Ah</td>
<td>60.8 V</td>
<td>₹25,000</td>
<td>£254.24</td>
</tr>
<tr>
<td>7</td>
<td>LiFePo4 Battery Pack</td>
<td>24 Ah</td>
<td>48 V</td>
<td>₹18,500</td>
<td>£188.14</td>
</tr>
</tbody>
</table>

### III. MODELLING OF THE CHARGING STATION

The battery used by the charging station has voltage and capacity of 48V and 24Ah respectively, thus it can be charged in 4 hours using a charger of 48V and 6A. A battery can be charged in two hours with a 12A charger. A 24 Ampere charger, on the other hand, can charge a battery in one hour. Furthermore, if a 48A charger is used, a battery can be charged in half an hour. On one charging station, these four chargers are used. This charging station can be expanded by adding extra charging points, such as one set of four chargers with one current rating and four sets with four different charging ratings. The time is calculated for a 100% battery charge, but the battery can only be discharged up to 80% in this study, therefore the time is reduced even more. The ratings of the chargers and their charging times are shown in Table III when the battery is charged and discharged up to 80%.

### TABLE III. TYPES OF CHARGERS

<table>
<thead>
<tr>
<th>No</th>
<th>Charger Type</th>
<th>Charging Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6A</td>
<td>3 Hours &amp; 12 Minutes</td>
</tr>
<tr>
<td>2</td>
<td>12A</td>
<td>1 hour &amp; 36 Minutes</td>
</tr>
<tr>
<td>3</td>
<td>24A</td>
<td>48 Minutes</td>
</tr>
<tr>
<td>4</td>
<td>48A</td>
<td>24 Minutes</td>
</tr>
</tbody>
</table>

A MATLAB model consists of several independent systems, each having its own set of controllers and batteries. This model has a complete set of 4 chargers in the charging station as depicted in Fig. 1. The maximum power point, often known as MPPT, is tracked using the P&O technique. The approach to demonstrate the MPPT algorithm is depicted in the diagram [8].

Once the maximum power from the PV system is attained, a controller is used to keep the current at 6A. The
backup battery system is introduced to store power and provide energy to the system during the charging process when the power generation is low. All of the chargers with distinct currents are displayed in the model schematic below.

All of the chargers, including the backup battery system, are connected to the PV system. At the point of connecting, all connections are parallel.

A. Backup Battery and Scopes

The voltage of the backup battery is compared to 72V and maintained with the application of a controller, as shown in Fig. 2. This battery keeps the charger currents constant while the solar power decreases or increases in different weather situations. Scopes are also displayed in Fig. 3, which are used in this model to generate different waveforms, as well as mathematical blocks.

B. Slow Charger

The 6-ampere charger shown in Fig. 4, is a slow charger that is often used to obtain power because of its long life, which is explained in the next section. The current and voltage of this charger are controlled to a specified value. This charger begins to operate immediately once the simulation begins to run. When this charger is turned on, the excess power is used to charge the backup battery because charging a single battery at 6A does not require much power.

C. Fast Charger

This is a 12A charger that takes less than two hours to fully charge the battery. This charger turns on after the first charger has been turned on for a while. When this charger switches on, the amount of energy used to charge the backup battery starts to drop.

D. Rapid Charger

This charger is very fast providing 24A current, taking less than an hour to fully charge the battery. This charger, like the others, minimizes the amount of energy used to charge the backup battery.

E. Super-fast Charger

This charger is exceptionally fast, supplying 48 amps of current to the batteries in just a few minutes. The charging current to the charging battery changes to a positive sign when this charger is turned on, showing that power is being delivered to the system. In less than half an hour, this charger can fully charge the battery. All of the chargers are designed in the same approach as the 6A charger, with the exception of the comparing of charge current levels, which are 6A, 12A, 24A, and 48A.

IV. RESULTS AND DISCUSSION

The circuit's efficiency, charging techniques, current and voltage levels, and power distribution between the solar and backup battery systems are all analyzed using the MATLAB model. This model has the credibility to charge the batteries under all weather conditions. This model has the potential to charge the batteries in all kinds of weather. When the sunlight and temperature change the amount of irradiance on different days and times, backup mechanism powers the batteries. The reliability of the design system is demonstrated in a variety of approaches. Many studies have been conducted on different types of batteries to determine their efficiency [9]. But in this research, we are checking the operation of a whole charging station using lithium-ion batteries.
A. The Sun Shines Brightly and Temperature is Normal

When the sun shines clearly and the temperature is normal (Irradiance of 1000W/m², and 25°C temperature), this technique is used to provide data that can be compared to different irradiance and temperature ratings. The simulation results of four chargers, backup battery and solar panel power are shown in Fig. 5, 6 and 7, respectively. Similarly, Fig. 8 and 9 show the total current and total power of chargers over time.

B. When There is Little Sunshine and Normal Temperature

If there is not enough sunshine and the temperature stays the same (750W/m² and 25°C), currents of chargers, backup battery and solar power are examined in Fig. 10, 11 and 12, respectively with respect to previous amount of sunlight.

C. When the Sky is Cloudy and Normal Temperature

Because if the weather is bad, it's pouring, and there are clouds in the sky (500W/m² and 25°C), it's necessary to test the model with decreased irradiance while maintaining the same temperature. In this situation, Fig. 13 shows current ratings of chargers while Fig. 14 and 15 show backup battery and solar power respectively, and any deviations are detected by comparing the variables in the current level of irradiance to the prior level of irradiance.
D. When Sunlight is Normal and Temperature Rises

In this example, the weather remains the same, but the temperature rises (1000W/m² and 40°C), with a different temperature value and the same level of irradiance to get different results. Similarly, the currents of 4 chargers and solar power are shown in Fig. 16 and 17.

E. Discussion

The results are derived through a comparison of numerous charger characteristics in various weather conditions in order to gain a thorough understanding of charging station performance. Here are some findings concerning the results of the examples provided above as waveforms.

- In the graphs where power is generated by the PV system, it provides full power at 1000W/m² in the given conditions. Solar power falls at 750W/m² as the solar system's irradiance diminishes, and it also decreases when the temperature rises from 25°C to 40°C.
- The extra power is applied to charge the backup battery when the batteries only require a little amount of energy to charge. It must be noted that when solar power declines, backup battery power is used to supply additional power to the charging batteries.
- The total current and power used by all chargers are the same in all cases and are unaffected by the weather.
- Thus, this has been proved that sunlight has no effect on the charger's voltage or current because the backup battery system gives the required power and also receives additional power from the PV system, as explained above. It can also have an effect if the PV system does not generate electricity for a long time but can function normally for a short time until the backup battery gives power.

V. Estimation of Battery Life

Delays in charging at regular intervals enhance battery life [10]. Temperature and charging or discharging current are also the major factors that cause battery life to degrade over time. The discharge current is kept constant at 12A since e-scooters can run on the road. This varies with the speed of the bike, but it is maintained constant in this example for simplicity. On the other side, the charging current is monitored to see how it affects battery life and what value should be used to increase battery life. As a consequence, a Matlab model is shown in Fig. 18 to obtain various outcomes.

Temperature and discharge current were tested at 25°C and 12A. The battery is only allowed to be depleted to a depth of 20% and no less. The battery is now charged with a 6A current, as shown in Fig. 19, and the results are analyzed to see how it impacts battery life over time as the number of cycles grows until the battery life begins to decline.

This is a combination of currents in which a discharging current is used to drain the battery, and then a charging current is supplied to charge it up to 100% when it hits 20%. And examine the time it takes for the battery's capacity to drop to zero and maximum age (equivalent full cycles), as shown in Fig. 20 and 21, respectively. Other battery measures, such as voltage and state of charge (SOC), show a similar trend.
If the battery is charged and discharged using the conditions listed above, such as charging and discharging current and temperature, it will take more than a year for the battery to decrease battery capacity to zero and achieve 2000 cycles. Although it is impossible to cover all cycles in a short period of time, this is a good example to learn how life declines. Now observe the results by increasing the battery charging current to 12A, as shown in Fig. 22.

In this arrangement, the charging and discharging currents are both 12A. So, charge and discharge the battery for the same amount of time to see an increase in the number of cycles of the battery in Fig. 23 and a decrease in the maximum capacity of the battery over time in Fig. 24.

The model waveforms demonstrate that when the charging current is increased to 12A while all other variables remain unchanged, the battery's age (Equivalent Full Cycles) and capacity decrease to zero in around three-quarters of the time it took in the preceding case. This illustrates that when the discharging current rises, the battery's life begins to decline. Similarly, all of the elements affect battery life, therefore they may be discussed more in further research.

The best charger for boosting battery life, according to the findings, is a 6A charger, which is also the most often used. Other chargers with higher currents are avoided when charging is required for a long period of time, and they are only used when significant charging is required in a short period of time.

VI. CONCLUSION

In Asia and India, the e-scooter sector is growing rapidly. As a result, Matlab/Simulation is being used to develop the charging station's hub. To begin, the battery attributes are established by comparing the e-scooters and batteries of various companies, and the model's operation, which includes solar panels, converters, and a backup battery system, is extensively described. Four distinct types of chargers are listed as compatible with a single charging station. Second, the circuit's effectiveness in delivering the required power to the batteries while preserving their voltage and current is supported by simulation results. Finally, a model in Matlab was created to estimate battery life, and varied results were obtained. When the results of various charging currents are compared, it is clear that the slow charger is the greatest option for extending the battery's life. In the future study, it will also be necessary to determine the battery's practical life by operating it for two or three hours every day for five years.

REFERENCES